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ON THE FLASHING PHENOMENA OF CERTAIN TYPES OF DISCHARGE TUBES

By JAMES TAYLOR B.Sc. AND WILLIAM CLARKSON M.Sc.

INTRODUCTION

The 'flashing' of discharge tubes was first described for the case of the Osglim lamp in a paper 'The Neon Tube as a means of producing intermittent currents' (Vol. 34 p. 204 Proc. Phys. Soc. Lond.) by Pearson and Anson. The present writers extended the study of flashing to the cases of air discharge tubes over a wide range of pressures.

(In one discharge tube with platinum wire electrodes, flashing was obtained down to a pressure of 0.07 mm. and the driving voltage was in this case about 950 volts. Under these conditions the negative glow almost filled the bulb of the discharge tube.)

Apart from the limit imposed by the voltage available there would appear to be no definite upper limit to the pressure at which flashing is possible.)

THE UPPER AND LOWER CRITICAL VOLTAGES

It was found both for the Osglim lamp and the air discharge tubes of various design, that under given conditions of temperature and pressure a definite potential across the electrodes—the sparking potential or upper critical voltage V_c —was required to initiate the discharge. This upper critical voltage was definite and repeatable to within a few volts provided the discharge remained under identical conditions but was subject to variations with the conditions of experiment (See later).

Provided that the discharge was once initiated, the voltage across the tube could be decreased to a very much lower value V_b —the 'going out' (extinction), or lower

critical voltage—before the discharge ceased. The flashing of discharge tubes depends upon the existence of these two voltages.

In the following experiments discharge tubes in which the electrodes were not more than some few mm's apart were utilized. This enabled the absence of the positive column and its concomitant phenomena. The conditions were thus much simpler than is usually the case since the Crook's Dark Space, the negative glow and the Faraday Dark Space with continually in anode glow were the only parts of the discharge in evidence.

THE PHENOMENON OF FLASHING

If a high resistance is connected in series with a source of voltage and with a discharge tube having a capacity C shunted across its electrodes the continuity of the discharge through the tube is interrupted and it flashes at regular intervals of time.* Between flashes the condenser which is shunted across the tube electrodes charges up from the lower critical voltage V_b to the upper critical voltage V_a and then discharges through the tube down to the lower critical voltage again. Pearson and Anson in their paper showed that the total time period (that is to say the time required for the condenser to charge up and then discharge through the tube) is given by the expression

$$T = kR \left\{ \log_{\frac{V}{V_b}} \frac{V - b}{r} + \frac{r^2}{R^2 C} \log_{\frac{a}{b}} \frac{a - Q}{b - Q} \right\} \dagger \quad (1)$$

In this equation the time of the luminous period, which

* If the tube is in complete darkness there is often a lag in flashing which disturbs the regularity of the flash. This may be completely overcome by having a bright light near the tube by having a radioactive substance near or in the case of the Osglum lamp by having another lamp under continuous discharge near it. All these devices provide sufficient ionization in the tube to overcome the usual lag in discharging.

† In this equation

V = the charging voltage

R is the resistance in series with the tube

K is the capacity across the electrodes

b and a the lower and upper critical voltages respectively and

$Q = \frac{V_r + rR}{R + r^2}$ where r is the reciprocal of the slope of the volt ampere characteristic and v_r is a constant

is the second term of the relation was deduced by utilisation of the empirical expression for the resistance of the glowing lamp and the voltage across the electrodes. The present authors utilized a simple theoretical derivation of the above relation (1) (see reference¹ at the end of the paper) and obtained in expression for the time period of the following very similar form

$$T = CR \left[\log_{\frac{E}{F}} \frac{V_b - V_a}{kR + 1} + \log_{\frac{V_a}{V_b - D}} \right] \quad (2)$$

where C is the capacity (in microfarads) across the tube terminals, R is the series resistance (in megohms), E is the charging voltage (in volts), F the conductance of the discharge tube (see next paper p 15) and D is an imprecise expression given by

$$D = \frac{F + kRV_a}{kR + 1} \quad \text{where } V_a \text{ is approximately the cathode fall of potential}$$

There is an alternative position of the capacity C for obtaining flashing in which the capacity is simply shunted across the high resistance R . The theory of this arrangement has been put forward in another previous paper where the time period relation is shown to be of exactly the same form as that given in equations (1) and (2).

In the case where kR is large compared with unity the relation of equation (2) may be approximated to the more simple form

$$T = CR \log_{\frac{E - V_b}{E - V_a}} + \frac{C}{k} \log_{\frac{V_a - V_b}{V_b - D}} \quad (3)$$

The time period of flashing should according to these relations be directly proportional to the capacity C over a range of capacities further since the first term of equation (2) is usually large in comparison with the second T should be a linear function of R the series resistance. When however the resistance becomes small the product kR progressively diminishes with R and the second term of equation (2) increases rapidly so that the law departs from the linear form F being of greater value than that given by the linear relation. It is also evident that T should be a linear function of the logarithmic term

In connection with the further investigation of the flashing phenomena the problem presents itself later of introducing resistances r_o or r_i into the circuit as shown in Fig 1

THE GENERAL PROBLEM OF THE EFFECT OF RESISTANCES ON THE FLASHING OF DISCHARGE TUBES

One of us (Taylor) has worked out the following general problem of the effect of resistances on the flashing of discharge tubes assuming a linear volt ampere characteristic

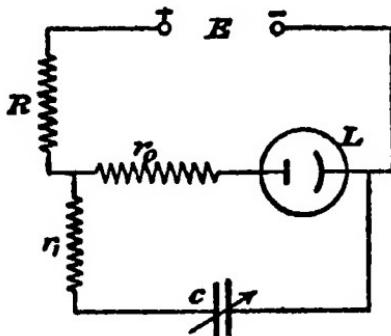


Fig 1

Let V_o be the potential across the tube at any instant V^1 the potential across the condenser and V the potential across r_o plus that across the tube. Then we obviously have the following relations holding

$$(I) \quad \frac{E - V}{R} + \frac{V^1 - V}{r_i} = \frac{V - V_o}{r_o}$$

$$(II) \quad \frac{V - V_o}{r_o} = k(V_o - V_a)$$

The voltage across the condenser at the end of the luminous period may be termed the apparent lower critical voltage V_b^1 , and is given when $V_o = V_b$. (I) and (II) then become,

$$(I)^1 \quad \frac{E - V}{R} + \frac{V_b^1 - V}{r_i} = \frac{V - V_b}{r_o}$$

(II)¹ $\frac{V - V_b}{r_o} = k(V_b - V_a)$, and from these we obtain

$$V\left(\frac{1}{r_o} + \frac{1}{R} + \frac{1}{r_i}\right) = \frac{V_b}{r_o} + \frac{E}{R} + \frac{V_b^1}{r_i}$$

and substituting for V we obtain an expression for V_b^1 , the apparent lower critical voltage,

$$\frac{V_b^1}{r_i} = \left[k r_o (V_b - V_a) + V_b \right] \left[\frac{1}{r_o} + \frac{1}{R} + \frac{1}{r_i} \right] - \left(\frac{E}{R} \right) - \left(\frac{V_b}{r_o} \right)$$

The apparent higher critical voltage is given from (I)

When the capacity is charging up we may neglect the tube electrode capacity in comparison with that of the condenser across the tube, hence in this case we may put $\frac{V - V_o}{r_o} = 0$, and assume that $V = V_o$ when discharge commences, and therefore $V = V_o - \left(\frac{E - V_o}{R} \right) r_i$

t_1 , the time for the condenser to charge up is evidently given by the usual form

$t = C(R + r) \log_e \frac{E - V_b^1}{E - V}$, and may be evaluated from the values for V_b and V obtained above

Now during discharge through the tube we have

(III) $-dq = \frac{V^1 - V}{r} dt$, where dq is the quantity of electricity flowing from the condenser in dt seconds. Or we may write (since $q = V^1$) substituting in (III) from (I),

$$-C dV^1 = \left[\frac{V - V_o}{r_o} - \frac{E - V}{R} \right] dt$$

also from (I), we have,

$$(IV) \quad \frac{dV^1}{r_i} = iV \left(\frac{1}{r_o} + \frac{1}{r_i} + \frac{1}{R} \right) - \frac{dV_o}{r_o}$$

From (II) we have,

$$dV = (k r_o + 1) dV_o$$

Substituting for dV_o in (IV) we obtain,

$$\frac{dV^1}{r_i} = A dV - B dV$$

writing $\frac{1}{r_o} + \frac{1}{r} + \frac{1}{R} = A$, and $\frac{1}{r_o(kr_o + 1)} = B$, and introducing the above value of dV^1 into (III) we obtain

$$-Cr(A - B) \frac{dV}{dt} = V \left[\frac{k}{(1 + kr_o)} + \frac{1}{R} \right] \left[\frac{E}{R} + \frac{V_o - k}{(1 + kr_o)} \right],$$

and the solution of this equation is the luminous period time t and gives,

$$t_2 = \frac{-Cr(A - B)}{\left[\frac{k}{1 + kr_o} + \frac{1}{R} \right]} \text{ Log}_e \frac{V_o - O}{V_b - O}$$

where,

$$O = \frac{E}{R} + \left(\frac{V_o k}{1 + kr_o} \right)$$

$$\quad \quad \quad \left(\frac{k}{1 + kr_o} \right) + \left(\frac{V_o K}{R} \right)$$

The total time period is of course given by addition of t and t_2 . It is easily seen that when $r_o - r = 0$, that the above form reduces to the ordinary formula of equation (2).

The above relations are, of course, worked out on the assumption of a linear volt ampere characteristic between the upper and lower critical voltages and the constancy of these latter voltages under different conditions, and as will be shown later these assumptions are only partially justified in practice.

THE EXPERIMENTAL RELATIONS

Pearson and Anson demonstrated the validity of their expression given in equation (1), to the case of the 'Osglim' lamp. The writers showed further for experiments on the same type of lamp, that the general empirical expression for results was,

$$T = R \left(\text{Log}_e \frac{E - V_b}{E - V_o} + B \right) + CF \quad (6)$$

B and C being constant when E is fixed.

Unfortunately in the case of the "Osglim" lamps it was only possible to conduct the experiments at one pressure (The pressure is approximately the minimum

voltage pressure for the neon helium mixture of gases with which the lamps are filled)

In the case of in discharge tubes, over a fairly wide range of pressures the authors have shown for the circuit arrangement in which the condenser is across the resistance R, that to a fair degree of accuracy the time period relation is represented by,

$$\Gamma = aCR \left(\log_e \frac{L - V_b}{E - V} - B \right) + \phi \quad (6)$$

where a , B , and ϕ are constants for a fixed pressure, " a " is always greater than unity, and B and ϕ are small constants

It is noticeable therefore that although the time period Γ is a linear function of C , R and the logarithm factor, yet owing to the introduction of the constant a , the experimental time period is in excess of the theoretical one. In some cases however, at certain pressures, " a " approached very near to unity. The anomaly may, of course be bound up in any of the variables C , R or the logarithmic factor or in a combination of them, and it was not found possible until quite recently to throw any light on the problem.

THE VARIATION OF THE UPPER AND LOWER CRITICAL VOLTTGES

The value of the upper critical voltage V_u has been found to vary somewhat under different conditions and it is important that it should be measured under conditions similar to those which will exist during the experiments.

V_u has a higher value initially than when the discharge has just ceased and is somewhat lower in value when rapid flashes are taking place through the tube, due presumably to the persistence, in some form or other of ionization around the cathode. Indeed when the value of the capacity shunted across the tube electrodes is such as to give (when a telephone is included in the circuit) notes of either audible frequency or higher the note may be maintained, provided that the discharge is once initiated, at values of E , the charging voltage, very considerably below

the normal value V_c , the upper critical voltage." Provided that flashes in which there is no great time period discrepancy are involved V_c is sufficiently constant for practical purposes.

It has been shown that the lower critical voltage V_b may vary considerably from its normal value according to the magnitude of the capacity across the discharge tube electrodes.²

In the case of the air discharge tubes on which the writers experimented, the lower critical voltage value V_b^1 under the existing conditions is usually greater than that given by the volt-ampere characteristics (see p. 12 of the present vol.) and increases with increase of the magnitude of the capacity across the tube. When the capacities are of the order of 1 microfarad the rate of change of V_b^1 is slow and V_b^1 may be regarded as almost constant.

Further work on the variation of V_b^1 under different conditions is in progress.

THE RESISTANCE CONDITIONS NECESSARY FOR THE MAINTENANCE OF FLASHING IN DISCHARGE TUBE CIRCUITS

It is obvious from a consideration of the conditions of flashing that it will be impossible to obtain any flashes whatsoever when the value of the circuit resistance R is decreased beyond a certain definite lower limit.

If we assume for the discharge tube a perfectly general volt-ampere characteristic instead of the linear form, we may write,

$$i = \Psi(V) \quad (7)$$

where i is the current through the tube, and $\Psi(V)$ is a continuous function of the voltage across the discharge tube electrodes. Let us consider the conditions during any instant of the luminous period, then if V is the voltage across the tube electrodes we have, the quantity of electricity flowing through the resistance R into the capacity from the charging battery is given by

$$dq_1 = \frac{E - V}{R} \cdot dt, \text{ in the time } dt \text{ seconds} \quad . \quad (8)$$

and the quantity of electricity flowing through the tube in the same time is

$$dq = \Psi(V) dt \quad (9)$$

Obviously if $dq > dI$, the discharge will become steady, for the loss of charge across the tube is balanced by the flow into the condenser from the battery.

The discharge therefore becomes steady when

$$\frac{E - V}{R} > \Psi(V) \quad (10)$$

Now since V has a range of values solely between the upper and lower critical voltages V_c and V_b (the lower critical voltage F is the existing conditions of experiment) the least value of R for which flashes can be maintained, consistent with the voltage limitations is given by

$$R_c = \frac{E - V_b}{\Psi(V)} \quad (11)$$

and this is a linear relation of E the charging voltage

In the case where the volt amper characteristic is linear and additional resistances r_o and r are introduced into the circuit as shown in Fig. (1) the writers, in a previous paper showed that³

$$R_o = \frac{F - (kr_o(V_b - V_o) + V_b)}{k(V_b - V_o)} \quad (12)$$

If $r_o = 0$ this becomes

$$R_o = \frac{E - V_b}{k(V_b - V_o)} \quad (12a)$$

and with $r_o > 0$ we have,

$$R_o + r_o = \frac{F - V_b}{k(V_b - V_o)} \quad (12b)$$

The above relations are obtained on the assumption of a change from the flashing to the steady state, and are valid solely under these conditions so that in obtaining the critical resistance R_c , R must be adjusted from larger to smaller values commencing initially with values well above the critical one.

Furthermore the conductance k of the discharge tube is not a constant for all ranges of capacity and condenser circuit resistances, and this is a point of some importance which must be considered later.

THE EXPERIMENTAL RELATIONS FOR THE CRITICAL RESISTANCES

In the preliminary experiments on the neon lamp it was ascertained that with no resistance in the condenser circuit (r_0 and r_1 resistances) the obtained values for the critical resistances were low, and consequently the currents through the tube were large. Under these circumstances the tube conditions were not very stable, due to the heating effects and the heavy charges thrown through the lamp during the luminous period and the obtained values of R_c are neither definite nor repeatable. It was for this reason that the r_0 and r_1 resistances were included in the circuit, for they decreased considerably the quantity thrown through the tube during discharge, and the conductance, as will be shown later, is much less than under normal circumstances when no condenser circuit resistances are employed.

The critical resistance point is very distinct in the neighbourhood of the critical resistance the time of flash increases very rapidly with decrease of R so that the T , R curve rises almost vertically to an infinite value of T , which corresponds to a steady discharge³.

As was shown in the above paper the relationship between the charging voltage E and the critical resistance function, for different values of r , in the two positions all proved to be linear functions which intercept the axis of voltage at a common point the ordinate of which has the lower critical voltage value for the tube. In all the neon tubes experimented with it was found by actual measurement that the voltage across the tube at the critical resistance falls to the lower critical value V_b .

The general form of the graphs was,

$$\frac{E - V_b}{R_c} = \text{const} = D \quad (13a)$$

for the case where $r_0 = 0$, and

$$\frac{E - V_b}{R + r} = D \quad (13b)$$

for the case where $r_1 = 0$

The constant D is, of course, the slope of the E , R , graphs, and is somewhat less in magnitude than the current at the critical resistance

"It would appear that so far as the critical resistance is concerned, r functions solely in regulating the effective conductance of the lamp. In the paper quoted, the empirical forms of the relations between D and r were put forward, and a tentative suggestion as to the physical significance of these relations was ventured. The following however, appears to be the correct way of regarding the effect of the r resistances.

VARIATIONS OF D , THE SLOPE OF THE E , R , GRAPHS WITH r

During the luminous period we have in essence, the capacity C acting as a source of voltage driving the discharge tube through a resistance r . It is thus a case for considering (see further p. 17 of this vol.) the volt-ampère characteristic for the tube

(1) With r of value zero and a linear volt ampere characteristic it is evident that,

$$i = k(V - V_a) = D$$

where k is the maximum conductivity of the tube, that is to say the whole area of the cathode is utilized in discharge

(2) With small values of r , the effect on the conductance of the tube will be inappreciable and D will be almost constant and of its maximum value

(3) As r increases it will regulate the magnitude of the current through the tube during the luminous period. Provided that r is sufficiently large the conditions will be those corresponding to the vertical portion of the volt-ampère characteristic (see p. 17) immediately after the discharge at the beginning of the luminous period has commenced the voltage across the tube will fall to the lower critical value to allow of the maximum current being carried by the tube, and as shown in the paper on the volt-ampère characteristics referred to, a portion only of the

kathode will be utilized in carrying the discharge. As the value of r is increased the area of electrode employed in flashing will progressively diminish, as indeed is found to be the case in practice³

(4) As the value of r is increased a point will be arrived at where the critical resistance condition given by equation (11) holds and the discharge will change discontinuously from the flashing to the steady state. This point is very definite in actual experiments.

(5) Finally as r is further increased a stage may be attained in which the total resistance in the circuit is greater than the critical resistance for the tube using the residual capacity of the circuit as its shunted capacity, and a high note (as observed by a telephone included in the circuit) will be produced. This latter observation is confirmed in practice, for when r is run up, a very high note is usually observable.

THE CRITICAL RESISTANCES FOR AIR DISCHARGE TUBES

In the case of air discharge tubes it was possible to design tubes suitable for the examination of critical resistances without including the usual r resistances.

The most suitable form had parallel wire electrodes of platinum or molybdenum, some few mms apart. These gave fairly consistent results.

For all the capacities used, the critical resistance function was found to be linear in accordance with the relation of equation (11), for all the pressures employed. V_1 the voltage intercept was, however, usually different from the normal value V_b for the particular tubes used. In the actual experiments with a capacity of 1 microfarad and pressures above 2 mms (approximately) V_1 was greater than V_b , for pressures of approximately 1 and 2 mms V_1 was approximately equal to V_b , and for lower pressures V_1 was usually somewhat less in value than V_b . (These relations are considered more fully in another paper.)

THE VARIATION OF THE CRITICAL RESISTANCES WITH CAPACITY

As the value of the capacity across the tube terminals was decreased, from high values (say 2 microfarads or so) the critical resistance was found in the case of the tubes used to decrease slowly with decrease of C down to about 0.004 microfarads. From this point downwards, however the critical resistance began to increase rapidly as C was diminished. This is apparently due to the very small energy transference possible during the luminous period, which makes the effective resistance of the tube high and correspondingly increases the value of the critical resistance.

In the case of very small capacities of the order of 10^{-1} microfarads for the air discharge tubes the critical resistance functions all proved to be linear within the limits of experimental error but the voltage intercepts were all greater than V_b .

Experimental results are thus in general accord with those predicted from the theory.

Certain results for the air discharge tubes would appear to indicate that the erratic results obtained for the voltage intercepts even at the same pressure may be intimately connected with the appearance and disappearance of an anode glow.

The authors wish to acknowledge here their indebtedness to Prof G W Todd under whose supervision the work was carried out.

REFERENCES

- (1) *Journ Sci Indus* Vol 1 No 6 p 174
- (2) See *Proc Phys Soc Lond* Vol 34 Pt 4 p 280 Discussion (Mr A Tarrant)
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ON THE VOLT AMPERE CHARACTERISTICS OF LOW TENSION DISCHARGE TUBES IN WHICH THE ELECTRODES ARE NEAR TOGETHER

By JAMES TAYLOR B.Sc

TYPES OF DISCHARGE

Low tension discharge tubes present many and interesting problems. One of the chief of these problems is the form of the volt ampere characteristics.

In the early work on discharge tubes the distance apart of the electrodes was usually great (10 cms or more) and the positive column with its concomitant phenomena were present. The effect of the accumulation of charge on the walls of the tube was considerable and could not be allowed for so that the results were on the whole neither reliable nor repeatable.

It is necessary at the outset to distinguish between two very distinct and different types of glow discharge.

(1) In which the positive column and its concomitant phenomena are present.

(2) Discharges as obtained in tubes in which the electrodes are only some few mms apart and the positive column is absent. Under these conditions there is the usual Crook's Dark Space Negative Glow, and Faraday Dark Space. Under certain conditions there is in addition an Anode Glow.

It is with the discharge of type (2) that we are concerned in this paper.

THE DISABILITIES OF DISCHARGE TUBE WORK

Discharge tube work has, from its initiation suffered from grave disabilities. In the early work, the discharge was either in actual contact with, or in close proximity to the glass sides of the containing vessel. Accumulation of space charge on the sides took place and very erratic

results were frequently obtained due to this. Furthermore, the nature of the electrodes suffered progressive changes with time and treatment. This resulted in very serious alterations in the value of the cathode fall of potential and the conductance of the tube. Finally a 'clean up' of the filling gas resulted in grave pressure changes which were productive of inconsistent results.

The first disability may in the main be overcome by utilisation of containing vessels sufficiently large to ensure that the electrodes are far removed from the sides and by having the electrodes close together. Reasonable stability of the electrodes can be obtained by making them of refractory metals like platinum or molybdenum and "overrunning" the tube for long period of time reversing the terminals from time to time and finally "overrunning" in one direction. The cathode is quite bright after this treatment and the anode is covered with a thin, uniform metal like film. When the latter deposit is produced and the discharge spreads itself uniformly over the electrodes it is judged that the electrodes of the tube have become sufficiently stable. Nevertheless progressive alterations in the constants of the discharge tube occur.

The last disability is overcome by having the tube in connection with a large ballasting vessel which averages up any pressure changes over the time of experiment.

THE CHARACTERISTICS OF DISCHARGE TUBES WHEN NO RESISTANCE IS INCLUDED IN THE CIRCUIT

The author showed in a previous paper that, with certain assumptions it was possible to derive theoretically a volt-ampere characteristic of the linear form¹

$$i = k(V - V_e) \quad (1)$$

where i is the current through the tube (usually measured in microamps), V is the voltage across the tube terminals, V_e is the cathode fall of potential approximately, and k is the "conductance" of the discharge tube.

The above relation agrees substantially with those derived practically for the neon lamp over a portion of the characteristic.²

In the case of air discharge tubes experiments by the writer on the form of the characteristics were not very satisfactory. The method used in the experiments, although by no means free from objections and difficulties, yielded over a range of pressures (to a fair approximation) a general linear form,

$$i = k(V - M) \quad (2)$$

M , which is of course the voltage intercept and should be of the value V_a , was almost constant in certain discharge tubes for different pressures and was of the correct order of magnitude. It is almost certain however that in the case of parallel wire discharge tubes that the form of the characteristics will depart from linearity.

The theoretical considerations which follow, do not depend upon the linearity of the volt ampere characteristic which may be assumed to be of the perfectly general form,

$$i = \psi(V) \quad (3)$$

where i is the current through the tube and $\psi(V)$ is a general function of the voltage across the discharge tube electrodes.

THE PHENOMENA OF FLASHING

The phenomena of "flashing" have been considered in the previous paper (page 2) and need not be entered into again, here. It was furthermore shown that there was a critical value for the resistance in series with the tube, below which no "flashes" could be obtained, given by,

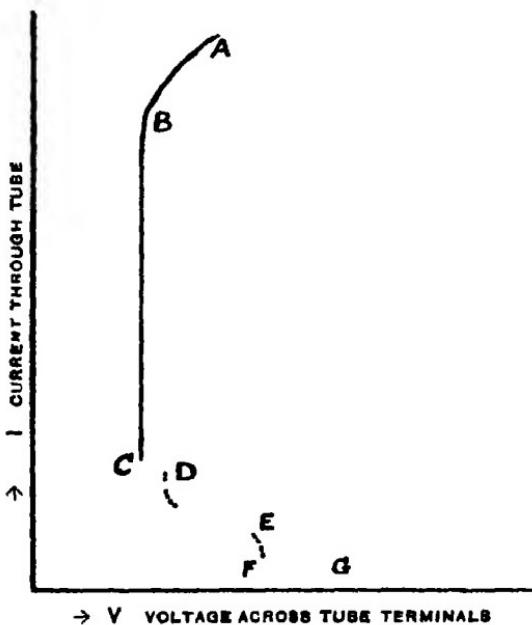
$$R_c = \frac{E - V_b^1}{\psi(V_b^1)} \quad (4)$$

where E is the charging voltage and V_b^1 is the lower critical voltage for the tube.

THE VOLT-AMPÈRE CHARACTERISTICS FOR THE DISCHARGE TUBES

The volt-ampère characteristics have been examined by the writer in the case of the neon lamp² and later in the cases of air discharge tubes of various design, and at differ-

ent pressures. Fig. (1) shows the general trend of these characteristics which are obtained by connecting the tube to a source of voltage through a high resistance and progressively diminishing this at the same time taking the corresponding readings for the current through the tube and the voltage across its terminals (by means of a microammeter and electrostatic voltmeter respectively)



The characteristic is of an illustrative nature and is not to scale the ordinates of the D to G portion being very much magnified to show clearly the various portions

FIG. 1

THE ANALYSIS OF THE CHARACTERISTIC

The characteristic as may be seen from the figure, comprises several very distinct portions

- (1) When the resistance in series with the tube is high (usually of the order of tens of megohms) the portion of the characteristic in the neighbourhood of G is obtained,

and we are here getting simply the Townshend current through a gas⁴

(2) As the resistance is decreased the current becomes intermittent in nature and a grating irregular noise is obtained in the telephones placed in series with the tube

When further reduction of the series resistance is made the characteristic becomes almost vertical over a range of currents (L to I approximately) that is to say the voltage is constant over a range of the characteristic

(3) As the resistance is further diminished a regular note (in the telephone) which increases in pitch with diminution of the resistance is obtained. The voltage across the tube (that is the average voltage as measured by the electrostatic voltmeter) decreases uniformly as the current increases. In the neighbourhood of the point D, however, the voltage again becomes approximately stationary with increase of the current at D the note in the telephones falls somewhat and the current changes discontinuously from the periodic to the continuous state. An abrupt fall of the potential across the tube electrodes (in some cases of up to 20 volts) and an increase in the current through the tube occur at this point. Further at this point the area of the cathode illuminated during discharge becomes abruptly less but the intrinsic luminosity of the negative glow increases.

(4) With further reduction of the circuit resistance, the voltage across the tube remains constant whilst the current increases. As the current increases a corresponding increase of the area of the cathode illuminated by negative glow takes place until finally the whole area of the electrode is employed in discharge in the neighbourhood of the point B

(5) With further decrease of the resistance in the circuit, the characteristic departs from the linear form, the voltage across the tube terminals rising rapidly as the current increases

THEORETICAL DISCUSSION OF THE VOLT-AMPÈRE
CHARACTERISTICS.

(1) When the resistance included in series with the tube is very high (giving the portion of the characteristic in the neighbourhood of G) the current obtained is simply the Townshend current through a gas, and the discharge is "dark."

(2) From D onwards to the right to F, the discharge is periodic in character and an intermittency of the current is thus produced. The current measured is thus the average current over the whole period, and the voltage is the average voltage.

The writer interprets this periodicity as being, purely and simply, a limiting case of the ordinary flashing phenomenon of the tube (see p. 2 of the present vol.), the residual capacity of the circuit and leads, and the electrostatic voltmeter which is across the tube terminals, acting as the condenser for charging and discharging.

The current is thus given by.

$$(5) \quad i = \frac{\int i \cdot dt}{T}, \text{ where } i \text{ is the instantaneous value of the current through the tube at the time } t, \text{ and } T \text{ is the total time period of flashing.}$$

The voltage is similarly given by,

$$(6) \quad V = \frac{\int v \cdot dt}{T}, \text{ where } v \text{ is the instantaneous value of the voltage across the tube at the time } t.$$

On the part of the characteristic to the right of F, the time of the "dark" period becomes long in comparison with the "luminous" period and as a consequence V , the upper critical voltage, varies erratically in value, due to "lag" effects, etc. The resultant note is therefore of a grating and erratic nature.

It will further be seen from the following discussion, that the average voltage across the tube, when the dark period is long compared with the luminous period, will be constant over a range of currents. This appears to be the explanation of the point of inflection in the volt-ampère characteristic at E.

THE AVERAGE VOLTAGE ACROSS THE DISCHARGE TUBE ELECTRODES.

We shall assume in the following discussion that the volt-ampère characteristic is linear between the upper and lower critical voltages, and that the net effect of the circuit capacity and electrostatic voltmeter is that of a capacity C , shunted across the tube electrodes.

The general form of the limiting cases which are to be considered would not be affected to any great extent by a departure of the characteristic from the linear form, but it is not of course possible to derive the average voltage across the tube electrodes directly, in the case of a perfectly general characteristic.

(A) Considering the "dark" period or the period during which the capacity across the tube electrodes is charging up, we have,

$$dq = \frac{E - V}{R} \cdot dt.$$
 Where dq . is the quantity of electricity which flows into the capacity via the circuit resistance R in the time dt . seconds.

Or we may write this,

$$C \cdot dV = \frac{E - V}{R} \cdot dt. \quad (a)$$

where C is the value of the capacity across the tube.

Integrating equation (a) we obtain,

$$V = E(1 - e^{-\frac{t}{CR}}). \quad (b)$$

Now the total time-voltage integral over the "dark" period is,

$$= \int_{V=0}^{V=V_c} V \cdot dt. - \int_{V=0}^{V=V_b} V \cdot dt.$$

and introducing the value of V from equation (b) we obtain,

Integral time-voltage

$$= E \left| t + CR e^{-\frac{t}{CR}} \right|_{V=0}^{V=V_c} - E \left| t + CR e^{-\frac{t}{CR}} \right|_{V=0}^{V=V_b}. \quad (c)$$

Now we have the following relations holding,

$$V = 0, \text{ when } t = 0,$$

$$V = V_b \quad , \quad t = t_b,$$

and $V = V_e \quad , \quad t = t_e.$

Introducing these values into equation (c) the time-voltage integral becomes,

$$E \cdot \left\{ (t_e - t_b) + C \cdot R \cdot \left[e^{-\frac{t_e}{CR}} - e^{-\frac{t_b}{CR}} \right] \right\} . \quad (d)$$

Now obviously from (a) we have, $t_e = C \cdot R \cdot \log_e \frac{E}{E - V_e}$ and

similarly $t_b = C \cdot R \cdot \log_e \frac{E}{E - V_b}$, from which we have that,

$$e^{-\frac{t_e}{CR}} - e^{-\frac{t_b}{CR}} = -\frac{(V_e - V_b)}{E},$$

and the equation (d) for the time-voltage integral becomes if we introduce this value into it,

Time-voltage integral $E \cdot t_1 \cdot C \cdot R \cdot (V_e - V_b)$. (e)
where t_1 (the time for charging) = $t_e - t_b$.

In addition we have from equation (a), $t_1 = C \cdot R \cdot \log_e \frac{E - V_b}{E - V_e}$.

(B) Considering the discharge or luminous period we have $-dq = k(V - V_a) \cdot dt = \frac{E - V}{R} \cdot dt$.

where dq is the nett loss of charge by the condenser, in the time dt seconds, k is the conductance of the discharge tube and V_a the cathode fall of potential approximately.

Now $-dq = -C \cdot dV$. so that the above equation may be written in the form,

$$-C \cdot dV = k(V - V_a) \cdot dt = \frac{E - V}{R} \cdot dt . \quad (f)$$

and integrating this equation we obtain,

$$V = D + (V_a - D) \cdot e^{-\frac{1+KR}{CR} \cdot t} \quad (g)$$

$$\text{where } D = \frac{(E + kRV_a)}{(1 + kR)}$$

Now the time-voltage integral over the luminous period is,

$\int_{V_v - V_b}^{V_e - V_b} V \cdot dt$. which, on introduction of the value of V from equation (g) becomes,

$$\int_{V_v - V_b}^{V_e - V_b} [D + (V_e - D) \cdot e^{-\frac{1+kR}{CR} \cdot t}] \cdot dt = \\ \left| Dt + (V_e - D) \cdot e^{-\frac{1+kR}{CR} \cdot t} \left(\frac{CR}{1+kR} \right) \right|_{t=0}^{t=t_2}$$

where t_2 is the duration of the luminous period.

Now we have from equation (f) that $t_2 =$

$$\frac{CR}{1+kR} \cdot \log_e \frac{V_e - D}{V_b - D}$$

Introducing this into the equation and simplifying we have,

Total time-voltage integral over the luminous period

$$= Dt_2 + \frac{CR}{1+kR} [V_e - V_b] \quad \dots \quad \dots \quad \dots \quad (h)$$

The total time-voltage integral over the whole period is given by the sum of equations (e) and (h).

$$= Et_1 - CR(V_e - V_b) + Dt_2 + \frac{CR}{1+kR} [V_e - V_b]$$

and the average voltage over the whole period which is evidently given by

$$\frac{\text{Total time-voltage integral}}{\text{Total time period}}$$

$$= \frac{E \cdot t_1 - CR(V_e - V_b) + D \cdot t_2 + \frac{CR}{1+kR} [V_e - V_b]}{(t_1 + t_2)} \quad . \quad (7)$$

Now when t_1 , the "dark" period becomes large in comparison with t_2 , the luminous period, we have approximately (the voltage across the electrodes of the discharge tube is V).

$$V = E - \frac{(V_e - V_b)}{\log_e \frac{E - V_b}{E - V_e}} \left[\frac{(kR)}{1+kR} \right] \dots$$

and since kR is, under these conditions large in comparison with unity we may write approximately,

$$V = E - \frac{(V_e - V_b)}{\log_e \frac{E - V_b}{E - V_e}} \dots \dots \dots \quad . \quad (8)$$

It is therefore evident from this equation, when the "dark" period is long compared with the luminous period, that the voltage across the tube electrodes, as measured by an electrostatic voltmeter, will be approximately constant over a range of values of the circuit resistance.

We may point out here that the increase of V_c , the upper critical voltage, when the "dark" period becomes very long will modify the range of the voltage constancy and will give rise to a grating note in the telephones (referred to above).

(3) In the portion of the characteristic from E to D equation (7) should hold for the voltage across the tube.

If we write for the total time period $T = t_1 + t_2$, the above relation may be modified into the form,

$$V = E - \frac{\Delta t_1}{T} + \frac{CR(V_c - V_b)}{T} . \text{(approximately)}$$

where $\Delta = E - D$.

Now it is shown on p. 3 that $T - CR \text{ Const.}$, so that we have,

$$V = E - \frac{Dt_1}{T} + (V_c - V_b) . \text{Const.} \quad (9)$$

The time period T decreases rapidly as R is decreased, but the luminous period t_2 does not vary very much until the critical resistance is approached. It is therefore evident that the voltage V will decrease steadily with diminution of R, since the second term in equation (9) increases as R decreases, and the portion of the characteristic from E to D will be traversed.

When the value of the circuit resistance approaches to that of the critical resistance the luminous period becomes large compared with the "dark" period, and we have approximately that $T \approx t_2$. Equation (9) may under these conditions be written in the form.

$$V = E - D + (V_c - V_b) . \text{Const.} \quad (10)$$

or if kR is large compared with unity, D will be approximately equal in value to V_c and equation (10) becomes

$$V = E - V_c + (V_c - V_b) . \text{Const.} \quad (10)^1$$

and we see that the voltage across the tube in the neigh-

hood of the critical resistance will be of a constant value over a range of resistances (consistent with the assumptions involved in the above theory), as is seen experimentally from the characteristic curve itself.

As the resistance is decreased, a point is arrived at where the relation of equation (4) holds, no further flashing can be maintained in the circuit, and the current changes abruptly from the periodic to the continuous state. This point is of course D of the characteristic. Now since the discharge at D is periodic, the voltage V_o , indicated by the electrostatic voltmeter, is an average between the upper and lower critical voltages, that is some definite value between V_b^1 (the lower critical voltage under the conditions of experiment), and V_e (the upper critical voltage under the conditions of experiment).

Thus, $V_o > V_e > V_b$.

The current at the critical point (current - i_e) is similarly the average current over the whole of the period of charge and discharge. Now the maximum current in charging is given by,

$$\frac{E - V_b^1}{R} \text{ and the minimum current by } \frac{E - V_e}{R},$$

consequently we have,

$$\frac{E - V_b^1}{R} > i_e > \frac{E - V_e}{R}.$$

When the discharge has become steady, the tube will naturally adjust itself to carry the maximum current possible under the conditions, that is, the voltage across the tube terminals will become as small as possible (the lower critical voltage V_b .) for the maximum current is $\frac{E - V_b}{R}$. It is evident therefore that the voltage V_o across the tube, just before the discharge becomes steady, is greater than V_b , the voltage across the tube, for steady conditions. Consequently the voltage will fall abruptly to the lower critical value at the point D, from some definitely larger value.

The intermediate portion of the characteristic from D to C will be realizable fortuitously only, in practice.

At D the tube is flashing and the greater part of the cathode is utilized in the luminous period, the discharge does not appear to be very luminous because the energy transference per unit area of cathode is small. As soon as the discharge becomes steady the maximum current that the tube can carry is shown above $\frac{I}{R} = \frac{V}{R}$ and there will be just sufficient of the cathode not employed in discharge (that is to say covered with negative glow) to carry this maximum current. At the critical point D there will thus be an abrupt decrease in the area of cathode illuminated by the negative glow but the intrinsic luminosity will be greater because of the increased energy transference per unit area.

(4) With further reduction of R and consequent increase of the maximum current $\frac{I}{R} = \frac{V}{R}$ the area of the cathode surface employed in discharge will increase to meet the demands of the external circuit and the potential across the tube will remain at the lower critical potential value. The portion of the voltage characteristic of the discharge tube from C to B is therefore characterized by the equation

$$i = \frac{L - V_b}{R} \quad (11)$$

(5) The characteristic is parallel to the axis of current until the point B is reached where the full cathodic area is utilized in discharge. If k is the maximum conductance of the tube we will now have if i is the current through the tube,

$i = k(V - V_b)$ where V is the voltage across the tube, and also, $i = \frac{E - V}{R}$. Solving this simultaneous equation we obtain an expression for the current in terms of known quantities

$$i = \frac{E - V_b}{\frac{1}{k} + R} \quad (12)$$

This relation is of exactly similar form to the empirical equation given by J. W. Ryde in the case of the "osglim" lamp for the part of the characteristic just beyond B.

The volt-ampère characteristic in the neighbourhood of the point B of full cathodic area employed, may be distorted from that given by the above consideration of a perfect case, for the distance between the electrodes usually varies from part to part (especially in the case of the "osglim" lamps which have large cathodes and small anodes) and the tube may act as a more or less composite tube having several lower critical voltages. Furthermore, the heating effects when the current is as great as it is under these circumstances tend to make the results unreliable.

CERTAIN EXPERIMENTAL RESULTS AND DIFFICULTIES.

As was stated previously the writer determined the characteristics in the case of the "osglim" lamp, and later in the case of air discharge tubes of various design, and at different pressures of the contained air. The characteristic of Fig. 1 is the general result, but it has not been possible so far to determine the portion of the characteristic to the right of C with sufficient accuracy and repeatability to compare the theoretical with the experimental results. Some of the difficulties inherent in the comparison have been pointed out already, the chief one nevertheless has been the voltage supply. Up to the present it has not been possible to obtain a suitably high voltage free from erratic fluctuations; these of course, inhibit any accurate comparison. In one or two cases where it was possible to make a comparison of the values of the potential for the constant voltage interval E to F, as obtained theoretically and experimentally, the agreement was fairly good. The author however, hopes, in the near future, to have at his disposal a source of voltage sufficiently constant to enable a full comparison of experimental and theoretical results to be made.

Furthermore, in certain recent experiments on the

region of the characteristic from C to B, the object of which were to show that the volt-ampere characteristics are parallel to the axis of current over a considerable range (as is described above), a tube of large cathode area consisting of an "osglim" lamp of the "beehive" variety (the lamp comprises an anode in the form of an iron disc, and a cathode of spiral form, in thick iron wire, wound above it), sealed on to an apparatus so that at different pressures could be introduced, was employed. In experimenting with this tube a very curious effect was observable in the region C to B of the characteristic. The following description is quoted from a letter to "Nature":

"It was observable at certain pressures that, when the discharge was continuous, but failed to cover completely the cathode, the discharge shifted from one part to the other of the cathode surface often undergoing a regular cycle. At other times the motion was along the wire of the spiral, slowly backwards and forwards through a rotation of up to 120° , and even more. The rotation continued over long periods of time in a most interesting manner."

"The phenomenon is apparently an electrode 'fatigue' effect. When one portion of the surface has been serving as cathode for some time, it becomes 'fatigued,' and the value of the cathode fall of potential rises, it then becomes easier for the discharge to pass over at an adjacent portion of the cathode, and consequently the discharge rotates slowly."

"That the rotation is accompanied by a corresponding fluctuation of the voltage drop across the tube is evident from the fact that the reading of the voltmeter, across the tube, rises and falls at a similar rate (there is of course a lag), and to a lesser degree variation of the current is observable."

To obtain readings for the characteristics of the tubes, the current and voltage are read each time, when the discharge is passing between the same portions of the electrodes (or in the same vicinity since the cathode area employed in discharge is increasing).

The range of the portion of the characteristic from C to

B was found, in certain cases, to be as great as 30 milliampères.

THE INTERMITTENCY OF CURRENTS IN DISCHARGE TUBES.

Intermittency of currents in discharge tubes has been observed by many experimenters, but so far, as far as the author is aware, the results have not been linked up with the ordinary flashing phenomena of discharge tubes.

As far back as 1898 Capstick (Proc. Roy. Soc., LXIII. p. 356), whilst measuring the cathode falls of potential for compound gases, noticed that in the case of these gases it was extremely difficult to obtain a continuous discharge, and intermittency was observed by the singing of a telephone included in the circuit.

Further, E Reiche (Ann der Phys. 4 F.B., 52, 1917, p. 109) observed intermittency in the case of air discharge tubes, when the circuit resistance was sufficiently high.

Aston and Watson in their measurements of the cathode falls of potential in the rare gases (Proc. Roy. Soc. A., 1912, 86, p. 176 and Proc. Cam. Phil. Soc., Vol. XVII., 1913, p. 90) observed that—

"When the current was passing through the gas, the voltmeter being disconnected, the pressure was reduced until the dark space just reached the anode. If then the pressure was very slightly further reduced or the current made lower by increasing the external resistance the current ceased to pass continuously, and passed in flashes. By careful adjustment these could be made to succeed each other with great rapidity, or at regular intervals as far apart as a quarter of a minute."

Watson also noticed an abnormal form of the rare gas discharge in which the glow is over the surface of the anode. The present writer has noticed a similar form of discharge in the "osglim" lamps, for the portion of the characteristic near F. The intermittency on this portion of the curve is characterized by the very minute area of electrode utilized in the discharge, this of course increases as the characteristic is traversed to the left, until frequently the whole cathode area is utilized before the critical resistance point is reached.

Appleton and West (*Phil. Mag.*, Vol. XLV., 1923, p. 879) have observed some very interesting oscillations in the striated glow discharge. They consider that these oscillations are purely ionic in nature and origin and independent of the conditions of the external circuit. As these oscillations occur in the stria, however, they are scarcely within the scope of the present work.

The author wishes to acknowledge his indebtedness to Prof. G. W. Todd, under whose supervision the experiments were carried out, and to the Department of Scientific and Industrial Research.

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SOME APPLICATIONS OF OSCILLATORY CIRCUITS
TO THE MEASUREMENT OF SPECIFIC INDUCTIVE CAPACITY.

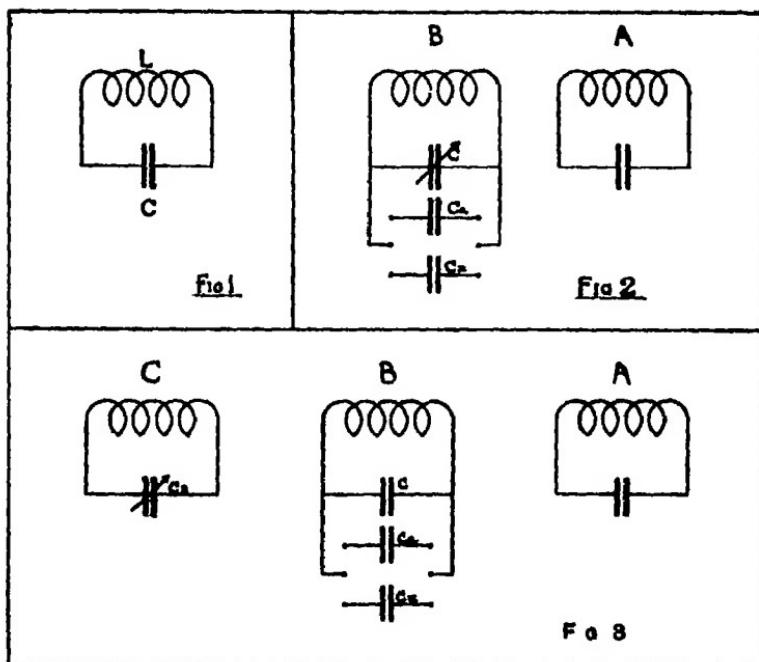
By LEONARD A. SAYCE, M.Sc., A.I.C.

INTRODUCTION.

For purposes that need not be described here the author recently desired to make precise measurements of the dielectric constants of certain non-conducting liquids. The various bridge and ballistic galvanometer methods for the measurement of capacity did not promise sufficient accuracy for the purpose, but it seemed likely that the triode valve would provide a solution to the problem. By its means considerable accuracy had already been attained in the measurement of the dielectric constants of air and other gases by Gill,¹ Wagstaff² and others, but their methods were inapplicable to the measurement of large variations of capacity and therefore could not be utilized in the determination of dielectric constants much greater than unity. The methods to be described were, therefore, developed for this purpose. In each of them, a condenser, here called the "dielectric container" is filled with the dielectric under examination and its capacity compared with that which it has when exhausted or filled with air. The necessary measurements of capacity depend upon the properties of a valve-maintained oscillatory circuit: In such a circuit, Fig. 1, containing capacity C and inductance L , the natural frequency, n , is given by the formula: $n = \frac{1}{k\sqrt{LC}}$, where k is a constant, thus if the inductance remain constant: $n \propto \frac{1}{\sqrt{C}}$. It is evident that

¹ *Radio Rev.*, 2, page 450, Sept 1921. ² *Phil. Mag.*, 47, page 66, Jan. 1924.

changes in frequency arise from, and are a measure of, any change in the capacity C. Further, if, by means of a triode valve, an oscillatory circuit be made to oscillate at a frequency n and a second similar circuit be set up near to it having a frequency n' then each circuit will induce currents of its own frequency in the other. The currents in each circuit will combine with, or "heterodyne" each other to produce beats of a frequency equal to the difference between n and n' and these beats may be heard in telephones included in either circuit.



METHOD 1

In the method first employed two oscillating circuits A and B (Fig. 2) are arranged so that they are in approximate resonance. A calibrated variable condenser, C₁, is then varied slowly until the "beat-note" first observed has been reduced to zero frequency. The two circuits are then in exact resonance. The dielectric con-

tainer, filled with air, is then connected in parallel with C_1 and the latter reduced in value until the circuits are once more in resonance. The reduction in the value of C_1 thus measures the capacity of the dielectric container (C_s). The container is then filled with the liquid under examination and its capacity (C_s) re-determined in the same manner. The ratio of $\frac{C_s}{C_a}$ is the required dielectric constant (to a standard $k_{(air)} = 1$) at the frequency employed.*

The usefulness of this method was found to be limited by two important difficulties. The first is that of securing a variable condenser which could be set, read and calibrated with sufficient accuracy. None of the usual types of condenser fulfils these conditions sufficiently for the present purpose. A condenser, the capacity of which could be calculated from its dimensions, was considered but was open to objection.

The second difficulty in applying the method arose from the tendency of two high frequency circuits to force each other into resonance. This made it impossible to obtain slow beats between them and consequently the point of resonance was not sharply defined.

The second method was therefore proposed to eliminate these two sources of error by substituting the measurement of frequency for the measurement of capacity.

METHOD 2.

The principle of this method is shown in Fig. 3.

A is a circuit oscillating at a frequency n of the order of $10^6 \text{ - per second}$.

B is a similar circuit oscillating at a frequency n_1 , approximately equal to n , with constant inductance L and constant capacity C_1 .

C is a circuit calibrated to oscillate at a known audible frequency determined by the setting of its condenser C_2 .

* It was subsequently ascertained that a similar method had been worked out by Whiddington (*Cambridge Phil. Soc. Proc.* 20, page 448, Nov., 1921).

When C is the only capacity in B a beat note $n_1 - n$ is obtained and its frequency is measured by the audio-frequency meter C. If now the dielectric container be connected in parallel with C a different beat note is heard and its frequency $n_2 - n$ measured by C. Lastly the dielectric container still in parallel with C is filled with the dielectric under investigation and a third beat note of frequency $n_3 - n$ is obtained and measured. A mathematical analysis of the method showed that if

$$A - n = n_a \text{ and } X - n = n_s$$

then the dielectric constant is given by the expression

$$k = \frac{n - A)^2}{(n - X)^2} \cdot \frac{2n}{2n} \cdot \frac{X}{A} \cdot \frac{X}{A}$$

The form of the first two terms shows that if A and X were large then considerable errors would be introduced unless n the high frequency were known fairly accurately. The wave meter is liable for measuring this high frequency had however an error in the order of 1 per cent. Apart from this the method depends upon the precision of the audio frequency meter C and the possibility of reproducing its condenser settings.

It is thus evident that the measurement of frequency changes is attended by probabilities of error even greater than those occurring in the measurement of capacity changes.

METHOD 3

In the third method therefore a return is made to the principles of method 1 but with two important modifications —

(1) The attainment of a given high frequency by B is observed not by its resonance with A but by the production between A and B of beats of a definite frequency viz such as to produce slow countable beats with a third low frequency circuit C. Thus the procedure is as follows — With C only in parallel with the inductance of B A and B are adjusted so that their difference of frequency gives a musical note ($n - n$). The musical note given by C is then adjusted until its frequency is so nearly equal to $n_1 - n$ that slow beats are obtained, easily countable with

the aid of a stop-watch. Then, after connecting the air-filled dielectric container in parallel with C_1 , the latter is reduced until the same slow beat-frequency is again obtained.* The reduction in C_1 then measures the capacity of the dielectric container with air as the dielectric. The measurement is repeated with the given liquid as the dielectric in the container. As before, the second value divided by the first gives the dielectric constant of the liquid. The extreme delicacy of the method is evident from the fact that a change of one per second in the frequency of the slow beats represents a change of only one in a million in the frequency of the circuit B, if the frequencies of A and B are approximately 10^4 ~ per second.[†]

(2) A special variable capacity of novel design has been constructed to fulfil the exacting requirements of this method. It comprises six fixed-capacity condensers and a small one of variable capacity: it is analogous, if fact, to a set of weights and a rider. The small variable condenser is so designed that its calibration curve is strictly rectilinear, and all the fixed-capacity condensers are calibrated in terms of scale divisions of the variable condenser. Thus the unit of all measurements is the scale division of the variable condenser and, as a ratio and not an absolute measurement is sought, the absolute value of this unit is unimportant. The method, even at its present stage of development, will measure unknown capacities with an error not exceeding one part in ten thousand, so that, for dielectric constants between unity and five, the third decimal place can be defined with certainty.

From the principle of the method it is evident that by using higher frequencies it is possible to obtain greater precision, and progress in this direction is probably limited only by the difficulty of maintaining absolute consistency in the frequency of valve-maintained circuits.

* The same beat-note is obtained whether the frequency of C be equal to $n_1 - n$ or to $n - n_1$. The ambiguity may be avoided if n_1 always be kept greater than n .

[†] A method dependent upon this principle has been employed by Whiddington in the measurement of extremely small distances, vide *Phil. Mag.* 40, page 634, Nov., 1920.

ON X RAY CRYSTAL ANALYSIS

By J F WOOD M.Sc

Crystallographers have long recognized that a crystal is built up by the repetition in space of a certain fundamental unit. This unit is a parallelopiped containing the substance of an integral number of chemical molecules. This view which has been amply supported by X ray investigations gives an obvious explanation of the fundamental law of crystallography—the law of rational indices.

Imagining the structure indefinitely extended in space, an infinite number of points can be found in it which are related to the whole structure in exactly the same way. These points form one of the fourteen Bravais space lattices.

Regarding a crystal as a polyhedron it has certain symmetry elements—rotation axes, symmetry planes, etc. These symmetry elements are definitely determined in the majority of cases by such tests as etched figures, optical properties, and so on. Such tests as these have revealed the fact that crystals can be classified as belonging to thirty-two types, each type possessing certain symmetry elements. The existence of these thirty-two classes can be deduced from the law of rational indices.

This external symmetry is only a partial expression of the actual internal structure which until the method of X ray analysis was employed lay beyond the ken of crystallographers. Although the method of X ray analysis has its limitations chiefly on account of the absence of a general theory of X ray reflection, the method when allied with the theory of space groups enables us to go much further than has hitherto been possible.

It has been shown, and by different methods by Federov, Schonflies and Barlow that the structure of any crystal must be referred to one of 230 types or space

groups. Each space group is characterized by a series of operations consisting of reflections, gliding reflections, rotations, screws, inversions and translations, arranged in a way depending on the space group (See *Mathematical Crystallography*, Hilton.)

Now, in many cases it is found that although the observed spacing of certain planes of a crystal is in agreement with the value calculated from crystallographic data there are some whose spacing is a submultiple of the calculated value. These abnormal cases can usually be explained as due to the presence of screws or gliding reflections in the space group to which the crystal must be referred, and so give the clue to the space group.

In the case of oxalic acid ($C_2O_4H_2$, $2H_2O$) for instance, which is monoclinic prismatic it is found that the spacings of most crystal planes have the value calculated on the assumption that there are two molecules in the unit cell. The planes ($h \ 0 \ l$) where $h+l$ is odd as well as the (010) plane have spacings which are half the calculated value. These abnormalities are such as would be expected if the space group to which oxalic acid is to be referred is C_{2h}^5 . (See *Phil Trans., Series A*, Vol. 224, pages 221-257, Astbury and Yardley.)

The number of asymmetric molecules required to produce the necessary symmetry, in this case, is four per cell. Since, however, there are only two per cell, the molecule of oxalic acid must have some symmetry of its own. Theory shows that this must be centro-symmetry.

In the case of ammonium oxalate the observed spacings are in agreement with those calculated from crystallographic data on the assumption of two molecules in the unit cell. The (100) and (010) are, however, abnormal, showing the half spacing. Since ammonium oxalate is rhombic bisphenoidal its space group must therefore be Q, (see Astbury and Yardley, *Phil Trans.*, page 234) and the molecule must possess a diagonal axis. This axis coincides with the crystallographic c axis.

X-rays, then, in addition to determining the size of the unit cell and hence the number of molecules it contains, can, in favourable cases, also define the space group to

which the crystal must be referred. In the present state of development of the subject this is as far as X-rays can carry us with any certainty.

In fixing the actual structure the approximate constancy of atomic diameters, the presence of cleavages, etc., are useful. In cases where the molecule possesses very high symmetry the number of structural possibilities is much reduced. But in the absence of any method of detecting individual atoms in the crystal and of interpreting completely the intensities of the various orders of reflection, the method of X-ray crystal analysis can do little more than determine space group, in the general case.

NOTE ON A SIMPLE INFINITE PRODUCT

By J. L. BURCHNALL, M.A.

In one of his papers* Cantor discusses convergent infinite products of the type $\prod_{r=1}^{\infty} \left(1 + \frac{1}{a_r}\right)$ where the a_r 's are positive integers satisfying the conditions $a_r > a_{r-1}^2 - 1$. He shows that, given a real positive number N , integers a_1, a_2, \dots can be successively determined such that $\prod_{r=1}^{\infty} \left(1 + \frac{1}{a_r}\right)$ converges to N and that for a rational N the law of recurrence is, after some stage in the process, $a_r = a_{r-1}^2 - 1$. This latter result rests on the easily established fact that if $a > 1$ (whether integral or not)

$$a^{a-1} = \left(1 + \frac{1}{a}\right) \left(1 + \frac{1}{a^2}\right) \left(1 + \frac{1}{a^4}\right) \quad (1)$$

Cantor also gives without discussing the general theory, the product forms of certain quadratic surds, e.g. —

$$\sqrt{3} = \left(1 + \frac{1}{2}\right) \left(1 + \frac{1}{7}\right) \left(1 + \frac{1}{97}\right)$$

$$\sqrt{5} = \left(1 + \frac{1}{1}\right) \left(1 + \frac{1}{9}\right) \left(1 + \frac{1}{161}\right) \left(1 + \frac{1}{51841}\right)$$

in which after a certain stage the law of recurrence is $a_r = 2a_{r-1}^2 - 1$

In this note I establish the general formula for such a product and investigate the relation of the result to a certain continued fraction

If $a > 1$ and for every $r > 1$, $a_r = 2a_{r-1}^2 - 1$, then

$$\prod_{r=1}^{\infty} \left(1 + \frac{1}{a_r}\right) \text{ converges to } \left(\frac{a_1 + 1}{a_1 - 1}\right)^{\frac{1}{2}} \quad (2)$$

* Schlesilich's Zeitschrift, vol. XIV (1869). See also Hobson, Functions of a Real Variable, 1st ed., p. 48

$$\text{For } \frac{a}{a+1} \left[\frac{a+1}{a-1} \right]^{\frac{1}{2}} = \left[\frac{a^2}{a^2-1} \right]^{\frac{1}{2}} = \left[\frac{2a^2 - 1 + 1}{2a^2 - 1 - 1} \right]^{\frac{1}{2}} = \left[\frac{a_1 + 1}{a_1 - 1} \right]^{\frac{1}{2}}$$

$$\text{So } \left[\frac{a+1}{a-1} \right]^{\frac{1}{2}} = \left[1 + \frac{1}{a} \right] \left[\frac{a_1 + 1}{a_1 - 1} \right]^{\frac{1}{2}}$$

and by successive repetitions of the process

$$\left[\frac{a+1}{a-1} \right]^{\frac{1}{2}} = \left[1 + \frac{1}{a} \right] \left[1 + \frac{1}{a_1} \right] \quad \left[1 + \frac{1}{a_n} \right] \left[\frac{a_{n+1} + 1}{a_{n+1} - 1} \right]^{\frac{1}{2}}$$

If now $a > 1$ a_n clearly tends to infinity with n and $\left[\frac{a_{n+1} + 1}{a_{n+1} - 1} \right]^{\frac{1}{2}}$ tends to unity. Thus the required result is established.

$$\text{Writing } a = \cosh 2\theta \quad i = \cosh 4\theta \quad a_n = \cosh 2^n\theta$$

$$\left[\frac{a+1}{a-1} \right]^{\frac{1}{2}} = \left[\frac{\cosh 2\theta + 1}{\cosh 2\theta - 1} \right]^{\frac{1}{2}} = \coth \theta,$$

and

$$\coth \theta = \left(1 + \frac{1}{\cosh 2\theta} \right) \left(1 + \frac{1}{\cosh 4\theta} \right) \quad \left(1 + \frac{1}{\cosh 2^n\theta} \right) \quad (3)$$

The result (3) may also be deduced from (1) for

$$\begin{aligned} \coth \theta &= \frac{\cosh \theta + 1}{\cosh \theta - 1} = \frac{\cosh \theta (1 + e^{-\theta})}{e^{\theta} - 1} \\ &= (1 + e^{-\theta})^2 (1 + e^{-\theta}) (1 + e^{-\theta}) \quad \text{by (1)} \\ &= \frac{(1 + e^{-\theta})^2}{1 + e^{-\theta}} \frac{(1 + e^{-\theta})^4}{1 + e^{-\theta}} \frac{1 + e^{-\theta}}{1 + e^{-\theta}} \\ &= \left(1 + \frac{1}{\cosh 2\theta} \right) \left(1 + \frac{1}{\cosh 4\theta} \right) \end{aligned}$$

the discussion as to points of convergence being omitted.

The only restriction on i so far imposed is that $a > 1$. In what follows it is further restricted to positive integral values.

The finite products formed by taking the first r terms of the product $\prod_{r=1}^{\infty} \left(1 + \frac{1}{a_r} \right)$ provide a set of rational approximations $\frac{u_r}{v_r}$ monotonic and increasing, to the quadratic surd $\left[\frac{a_1 + 1}{a_1 - 1} \right]^{\frac{1}{2}}$.

The general formula is

$$\frac{u_r}{v_r} = \frac{(a_1 + 1)(a_2 + 1) \dots (a_r + 1)}{a_1 a_2 \dots a_r} = \frac{(a_1 + 1)}{a_1 a_2 \dots a_{r-1}} \cdot \frac{(a_{r-1} + 1)}{a_r},$$

and by successive reductions, using $a_r = 2v_{r-1} - 1$,

$$\frac{u_r}{v_r} = \frac{2^{r-1}(1 + a_1)a_2 \dots a_{r-1}}{a_r}. \quad . \quad . \quad . \quad (4)$$

The expression on the right is in its lowest terms, for

(a) a_r is odd.

(b) a_r, a_s have no common factor.

for if $a_s \equiv 0 \pmod{k}$ $a_{s-1} \equiv -1 \pmod{k}$,

and $a_{s-2} \equiv a_{s-3} \equiv \dots \equiv a_r \equiv +1 \pmod{k}$.

(c) $a_r, a_1 + 1$ have no common factor,

for if $a_1 \equiv -1 \pmod{k}$ $a_2 \equiv a_1 \equiv \dots \equiv a_r \equiv +1 \pmod{k}$.

Thus $u_r = 2^{r-1}(1 + a_1)a_2 \dots a_{r-1}$.

$$v_r = a_r.$$

Thus $\begin{cases} u_r = 2a_{r-1}u_{r-1} = 2u_{r-1}v_{r-1} \\ v_r = 2v_{r-1} - 1 \end{cases} \quad . \quad . \quad . \quad (5)$

It is natural to expect some connection between the product expression for $\left[\frac{a_1 + 1}{a_1 - 1} \right]^{\frac{1}{2}}$ and its expression as a continued fraction

$$\frac{a_1 + 1}{a_1 - 2a_1} \frac{1}{2a_1 - 2a_1} \frac{1}{\dots} \dots \dots \quad . \quad . \quad . \quad (6)$$

with negative partial quotients, the successive convergents of which likewise furnish a set of monotonic increasing approximations.

Consider the continued fraction

$$y = \sqrt{a^2 - 1} = a - \frac{1}{2a - \frac{1}{2a - \frac{1}{2a - \dots}}} \quad . \quad . \quad . \quad (7)$$

and let $\frac{p_r}{q_r}$ be the r^{th} convergent.

The $(r+1)^{\text{th}}$ complete quotient is $-(y+a)$

and so $y = \frac{(y+a)p_r - p_{r-1}}{(y+a)q_r - q_{r-1}}$

or $y^2 q_r + y(aq_r - q_{r-1} - p_r) = ap_r - p_{r-1}$

and comparison with $y^2 = a^2 - 1$ gives

$$\begin{cases} aq_r - q_{r-1} - p_r = 0 \\ ap_r - p_{r-1} = (a^2 - 1)q_r \end{cases} \quad . \quad . \quad . \quad . \quad (8)$$

Write for brevity $2^{r-2} = a$, $2^{r-1} = \beta$.

From the continued fraction we have immediately

$$\frac{p_\beta}{q_\beta} = \frac{\left(a + \frac{p_\alpha}{q_\alpha}\right)p_\alpha - p_{\alpha-1}}{\left(a + \frac{p_\alpha}{q_\alpha}\right)q_\alpha - q_{\alpha-1}}$$

and so

$$\begin{aligned} p_\beta &= ap_\alpha q_\alpha + p_\alpha^2 - p_{\alpha-1}q_\alpha \\ &= ap_\alpha q_\alpha + p_\alpha^2 - 1 - p_\alpha q_{\alpha-1} \\ &= 2p_\alpha^2 - 1 \text{ using (8)} \end{aligned}$$

$$\begin{aligned} q_\beta &= aq_\alpha^2 + p_\alpha q_\alpha - q_\alpha q_{\alpha-1} \\ &= 2p_\alpha q_\alpha \text{ using (8).} \end{aligned}$$

Thus if $\frac{x_r}{y_r}$ is the 2^{r-1} th convergent

$$\begin{aligned} x_r &= 2x_{r-1} - 1 & x_1 &= a \\ y_r &= 2x_{r-1}y_{r-1} & y_1 &= 1. \end{aligned}$$

The identification of a with a_1 gives

$$x_r = a_r, y_r = 2^{r-1}a_1 a_2 \dots a_{r-1}$$

and the 2^{r-1} th convergent to $\frac{a_1 + 1}{a_1 - \frac{1}{2a_1 - \frac{1}{2a_1 - \dots}}}$

$$\text{is } \frac{a_1 + 1}{x_r} y_r = \frac{2^{r-1}(a_1 + 1)a_1 \dots a_{r-1}}{a_r}$$

That is, it is the r^{th} convergent of the infinite product discussed

The infinite product is, in fact, a very rapid condensation of the continued fraction.

THE LIMITS OF EXPLANATION IN BIOLOGY.

BY B. MILLARD GRIFFITHS, D.Sc.

The biologist, whether he be a botanist or a zoologist, deals with masses of matter. The study of matter in general is the domain of the physicist and chemist, and their ever-extending investigations reveal a world of phenomena exhibiting a unified orderliness and an invariability of sequence which apparently prevails in unbroken fashion from the minutest particle to the vastest star. The results of these labours are embodied in the great generalizations of the indestructability of matter, and the indestructability and conservation of energy. Thus if we take a lighted candle as an example, physicists and chemists assert that the matter composing it, and the energy it is capable of giving out during combustion, are absolutely constant, but that when the matter of the candle becomes water vapour and carbon dioxide at a uniform temperature, no further changes are possible. The matter and the energy are constant, but at the end, the energy is dissipated.

In a similar way, the energy which a living mouse or a living man can derive from a given quantity of food, is also a constant, and when that food is consumed in the process we call respiration, there is a similar process of energy production and final dissipation.

The energy balance for burning candle and respiring organism is one and the same, and the end results are identical. It is very easy to reach the conclusion that the living and the non-living are therefore identical in every respect, and a considerable school of biologists do reach this conclusion. Nevertheless the deduction cannot be admitted as it stands, for the following reasons.

Taking the burning candle as an example of a non-living thing, its energy history is very simple. It under-

goes a process of molecular change in which carbon compounds combine with the oxygen of the air and become water-vapour and carbon-dioxide. There is a linear progression from matter which is capable of giving out energy, to matter which is less capable of giving out energy. At each step in the progression, energy is set free in the form of heat and light and the final state is a volume of gases at uniform temperature. The energy becomes dissipated, and the matter of the candle is no longer capable of undergoing further change. What is also of very great importance as far as our present purpose is concerned, is the striking fact that the candle itself ceases to be candle and becomes something quite different namely a volume of gas. The matter of the candle is constant but the candle as such, has ceased to exist. It gives out energy but at the price of its own destruction.

The energy history of the living organism is however, very different. The mouse for instance, remains absolutely intact and in the form of its offspring remains eternally intact, in spite of the fact that it is perpetually self-consuming. The mouse and all other living things, have the extraordinary and unique property of using some of the energy set free from their decomposing substance, to take hold of matter external to themselves, and to incorporate that extraneous matter into their own substance. The living thing is perpetually disintegrating like a burning candle, but unlike a burning candle is just as perpetually reconstructs itself at the expense of extraneous matter.

The living thing, therefore, is not a mass of matter in the same sense as the candle or any other non-living thing. The candle ceases to be a candle when its matter has changed from a solid to gas but the mouse, in spite of the fact that the matter of which it is composed is perpetually changing, nevertheless just as perpetually remains a mouse. As long as matter is living, it continues to retain its identity amidst ever-changing substance, and this extraordinary property is shown by no other matter than that which we call "living".

There is yet another property confined to living matter

alone. If a jet of air of known velocity and volume is directed upon the flame of the candle, the flame is deflected to a degree which is absolutely constant. The deflection can be calculated, and however many times the experiment is repeated, the same result is obtained. The reaction is strictly proportional to the force acting, and the effect is simply the summation of the forces determining the shape and size of the flame, and those determining the shape and size of the impinging jet of air. The cause is one series of phenomena and the object affected is another, and the effect is the sum of the two. A added to B gives A + B.

If the jet of air is directed on the living mouse, the effect is a very different thing. The living mouse is one series of phenomena and the jet of air is another, but the subsequent shape, size and position of the mouse is not the mere sum of the two. The mouse reacts to the impinging jet, the jet causes an effect, but the effect bears no direct relation to the cause. A is added to B, but the result is not A + B. The cause of the change in the mouse is not a cause in the same sense as the cause of the change in the flame. The flame reacts to a force acting upon it; the mouse responds to a stimulus. In the flame, action and reaction are merely an addition sum whose answer can be predicted. In the mouse, the reaction is a response to a stimulus, and cannot be predicted. In the case of the mouse, the jet of air is a signal only, and what will be the response to the signal, it is not possible to say.

These considerations must therefore give us pause whenever we begin to apply physico-chemical methods of investigation to living things. Caution is peculiarly necessary at the present time because there is a school of Behaviourists which in its otherwise laudable desire to unify knowledge, assumes that the phenomena of living matter are one and the same with the phenomena of non-living matter, and that the methods and results of the physicist and chemist can be applied without qualification to the living things with which the biologist has to deal. The attempt to interpret the phenomena of life in terms of physics and chemistry is perfectly legitimate provided it

is recognized that such an explanation cannot be complete, but to assume that complete explanation is possible and to ignore obvious differences only leads to explanations which sometimes verge on the ridiculous.

Let us first be quite clear what is meant by the term explanation when used by the biologist who is desirous of interpreting living phenomena in chemico physical terms.

To return to our lighted candle what is the explanation of the change in shape of the flame when a jet of air impinges upon it? Why does the candle flame change its shape?

We say that the particle of air travelling at a certain velocity strike the particles of gas which are rising from the flame also at a certain velocity. When the two streams of particles meet the direction of the stream of gas from the flame is the resultant of the two interacting forces as in the familiar parallelogram of forces.

Now whether this explanation is scientifically correct or not the explanation as such is merely the insertion between two observed phenomena of a series of other known phenomena and the whole series forms a coherent chain or network. As long as the chain is coherent however many insertions are made the explanation is said to be correct and if the chain includes all known phenomena the explanation is said to be complete. We see how the flame acts and now we know why. Similarly one can explain the change of the lighted candle into carbon dioxide and water vapour by inserting a series of known molecular interactions between the state of the candle before and after the combustion.

Explanation therefore in these cases is merely recapitulation the simple interpolation of the items in an addition sum of which the first term and the result are known. If the inserted items and the first term total up to the known result the sum is complete the explanation is correct.

When we come to apply this method of explanation to changes in the living organism, we are at once met by the

difficulty that the phenomena exhibited by the living being are not the same as the phenomena shown by matter in general. The living thing exhibits unique properties which non-living matter does not, namely the power of perpetually maintaining its form amidst perpetually changing substance, the power of assimilating extraneous matter, of growing and of reproducing. The living organism from the chemico-physical point of view, is always the sum of known properties of the matter of which it is composed, plus those properties of re-creation, growth and reproduction, which are not properties of matter as the chemist and physicist know it. This means that in the phenomenal addition sum, there will always be an unknown quantity, and its presence will always prevent us being sure that the interpolated items in the sum do add up to the result observed. Before we can be sure of our result, it will be first of all necessary to interpolate a physico-chemical series of phenomena between the chemico-physical properties of the matter itself and the properties of that matter in the living condition. For instance it will be necessary to explain in what chemical and physical respects does the ultra-microscopic filter-passing virus differ from the colloidal molecular aggregates surrounding it. Why does the virus assimilate, grow and multiply, whereas the colloidal non-living particles do not? What chemico-physical series can be inserted between the phenomena of living mouse and the materially identical dead mouse? Until these questions can be answered, until they can be explained by a coherent series of known phenomena, it is not legitimate to ignore the fact that in the phenomenal addition sum of the living organism there is an unknown factor and we cannot therefore assume that our physico-chemical factors are the causes of the effects observed. Explanation in the sense of interpolating a known series of physico-chemical phenomena between the first item and the result, cannot therefore ever be complete.

If these contentions are correct, the explanations offered by certain schools of Behaviourists ought to be visibly unsatisfactory, but nevertheless whole books are written

crammed with explanations of animal and plant behaviour, and are apparently accepted as correct. How is this remarkable result obtained? It is done very simply and very beautifully by creating a kind of deity called **Tropism**.

To quote Mr. Flatteley (*Proc., U.D. Ph. Soc.*, VI, 2 p. 86), A tropism is an obligatory response under the direct compulsion of an external stimulus, as when a moth flies into the flame of a candle.

According to this definition the moth flies into the flame because it is compelled to do so by the external stimulus of the light from the flame, and the obligatory incineration is called a tropism. The definition is really an extraordinary one, coming as it does from a Behaviourist who is endeavouring to interpret the behaviour of living things in terms of physics and chemistry. The terms *compel* and *obliged* are not scientific words at all. Physical science knows only of invariable sequences. Necessity, compulsion and obligation are not words in its vocabulary but belong to a totally different realm of knowledge—the world of the psychologist and the philosopher. Their use by a Behaviourist at once arouses suspicion that legitimate explanation in physico-chemical terms has failed and that refuge has been taken in a branch of knowledge with which the chemist and physicist have nothing to do. This suspicion is confirmed by the fact that the explanation given is at once fortified by subsidiary pseudo-physical explanations which Mr. Flatteley quotes from Professor Loeb to the effect that when the moth's eyes are unequally illuminated the physiological symmetry of the brain is disturbed and this disturbance being communicated to the muscles of the unilluminated side they are thrown into a state of increased tension etc. etc." What may be the physico-chemical nature of the disturbance," or its communication is left in deepest obscurity, and under cover of that obscurity it is very easy to bring forth the "tropism" as an all sufficient explanation of what has not really been explained.

Suppose we take a case of behaviour which can be

completely explained in physico-chemical terms. Someone somewhere once invented a curious little toy dog. When a bright light was directed on the toy, it began to move its legs and walked towards the light, and if the light was shifted to one side, the dog promptly swung round and once more followed it. Examination of the dog showed that it contained two small electric motors, one to each pair of legs, and the motors were connected with the dog's eyes by wires. Now what is the physical explanation of the dog's behaviour? According to the Loeb school of Behaviourists the behaviour is due to a tropism, to an obligatory response to an external stimulus, to heliotropism in fact. They would go on to point out that when the two eyes are unequally illuminated the physiological symmetry of the creature is disturbed and the disturbance being communicated to the motor on the un-illuminated side, the motor is thrown into a state of increased activity and moves the legs on that side of the body.

But what is that disturbance, what is the chemico-physical explanation of the upset of physiological symmetry? What series of phenomena can be inserted between the incidence of the light and the response of the toy? "It is a tropism," says the Behaviourist. "The dog moves because it responds to heliotropic stimulus," and this is all one could get as an explanation. It becomes clear in fact that the explanation is no explanation at all, and the high-sounding phrase "heliotropism" is nothing more or less than a mere description of what happens. "Tropism" is only the statement of an observation, and the so-called "obligatory response" and "direct compulsion of an external stimulus," are only sounding phrases coined to cover up the fact that the explanation is not complete. The scientific Behaviourist would only be justified in saying that the toy dog responds to light, that its motors move when light falls on its eyes, but what series of known phenomena can be interpolated between light incidence upon the eyes and activity of the motors, it is impossible to say. The behaviour of the dog can be described but it cannot be fully explained, because there

is an unknown factor at work, there is a gap in the physical series which in the present state of knowledge cannot be bridged, and to cover ignorance by inventing a name for ignorance, is to say the least unscientific.

As the tropistic Behaviourist is quite content with his explanation one need not tell him that the dog's eyes contain pieces of selenium, a substance which changes its structure slightly under the influence of light, and consequently causes change in any electric current that may be passing through it at the time. Now once this physical series of phenomena is inserted between light incidence and motor activity, the explanation of the dog's behaviour in physico-chemical terms, is complete. "Heliotropism," invoked as a cause, is superfluous—as superfluous as the invocation of "geotropism" to explain the fall of a stone, and its invocation is clearly revealed as the illegitimate substitution of a mere descriptive term for an explanation.

Now our toy dog is merely a mass of non-living matter, and its properties are merely the sum total of the properties of its constituent parts, and its energy history is a linear series of energy dissipations during which the battery chemicals break down and the mechanical parts wear out and the toy perishes. Knowing the properties of its parts, its behaviour can be predicted and is invariable.

When we attempt to apply explanation to the case of the moth and its behaviour towards the candle-flame, we at once meet the difficulty that its matter does not only exhibit the properties of its constituent substances, but exhibits also a whole series of properties which matter in the non-living condition does not show, namely, those properties of re-creation, assimilation, growth and reproduction, not to mention those properties of psyche, mind, thought—call it what you will—which cannot be dealt with by the chemist and physicist. Furthermore, the behaviour of the moth is not by any means invariable, in spite of Mr. Flatteley's statement, or it would be the easiest thing in the world to rid a room of moths. The light of the candle no more compels the moth to fly towards it than the green signal light on the railway compels the driver of the train

to drive forward. The stimulus is a signal, and as far as we know, there is no physico-chemical connecting series between signal and response. The train driver will go forward not only to a green light but a green flag, a waving arm, a swung lamp or the words Right away! The whippet will dash away at the signal of a dropped handkerchief or a pistol shot or the word Go! but no one but a behaviourist would say that negative pistol-shoto-tropism or positive dropped-handkerchiefo-tropism was the physico-chemical explanation of the creature's behaviour.

It is possible that so careful a worker as Mr. Flatteley did not intend that his definition should bear the implications suggested, but nevertheless other workers go to even greater length in their invocation of tropism as the fetish which pulls them out of every difficulty. Thus Mr. Flatteley quotes (p. 88) "a favourite example of Loeb."

"The butterfly *Portesia chrysorrhœa* lays its eggs upon a shrub. The larvae hatch out in autumn and hibernate on the shrub, usually close to the ground. In Spring the caterpillars leave their self-constructed nest and crawl up the stem to feed on the young plant buds. Should they crawl downwards they would starve, but they never do crawl downwards. What is the cause of this remarkable behaviour? According to Loeb, the upward movement of the caterpillar is due solely to the influence of light upon the physiological processes taking place within the body. These processes, acting in relation with the symmetrical structure of the animal, bring about a movement directly towards the light. In other words the larvae on becoming active after their winter rest, are positively heliotropic. As soon as the caterpillars have eaten the few young shoots at the top of the plant, they at once turn downward. The upward tendency which at first saved the animal's life would now, if persisted in, lead to its downfall. What brings about this remarkable change of behaviour? Simply the fact that the process of feeding has effected changes in metabolism which result in the animal becoming indifferent to light; these chemical changes in fact abolish heliotropism. Experimental confirmation of the above

facts may be obtained by placing starved and fed caterpillars in separate test-tubes and submitting them to the same source of light. The unfed caterpillars will make their way towards the light and stay there, while the fed caterpillars remain completely indifferent."

Let us add a further example, strictly parallel and familiar to all of us. Certain creatures may be observed crawling about the corridors of Armstrong College. About one o'clock they are found to travel towards the refectory where they feed on soup, fish, joint and sweets. Should they crawl away from the refectory, towards the Zoo. Dept. for instance, they would starve, but they never do crawl that way. What is the cause of this remarkable behaviour? According to Loeb, the refectoryward movement of the creature must be due solely to the influence of the smell or sight of the soup, fish, joint, and sweets, upon the physiological processes taking place within the body. These processes, acting in relation with the symmetrical structure of the creature, bring about a movement directly towards the refectory. In other words, the creatures on becoming active after their confinement in lecture rooms, are positively soupo-fisho-jointo-sweeto-tropic. As soon as the creatures have eaten the food in the refectory, they at once turn away toward the Zoo. Lab. again. The refectoryward tendency which at first saved the creature's life would now if persisted in, lead to its scholastic downfall. What brings about this remarkable change of behaviour? Simply the fact that the process of feeding has effected changes in metabolism which result in the creature becoming indifferent to the smell and sight of the food; these chemical changes in fact abolish the soupo-fisho-jointo-sweeto-tropism. Experimental confirmation of the above facts may be obtained by placing starved and fed creatures of this species in separate rooms in the Zoo. Dept., and submitting them to the same smell from the refectory. The unfed creatures will make their way towards the refectory and stay there, while the fed ones remain completely indifferent.

When one puts forward "refectoriotropism" as an

explanation of the behaviour of living creatures within the College the absurdity of the suggestion is only too glaringly apparent. It becomes obvious that refectorio-tropism is merely a term describing the fact that these creatures behave in a certain fashion, but it is not in the least an explanation. In the same way the heliotropism of Loeb's caterpillars is merely a description of their behaviour and not an explanation of it; it describes the mode of behaviour, it describes the conditions which guide their movements, but it gives no physico-chemical explanation of their behaviour. The light is undoubtedly the signal to which the caterpillars answer, it is the stimulus to which they respond, it is the condition by which they are guided, but it is no more the chemico-physical explanation of their movements than the smell of cookery from the refectory is the chemico-physical explanation of our movements in Armstrong College. Far from Science being indebted to the Behaviourist for explanations of the tropistic type, it might be more truly said that Science owes Behaviourism a grudge for covering up a real difficulty with high-sounding terminology and pseudo-explanation.

Explanation in biology is strictly limited by the nature of explanation itself. As far as the world of physics and chemistry is concerned, the process consists of the insertion of more and more complete series of known phenomena between antecedent and consequent phenomena, the whole forming one coherent and interlocking assemblage of invariable phenomena. When the phenomena in question are those of non-living matter, the phenomena of energy systems which degrade in linear succession, the explanations are wonderfully complete, but when we try to deal with the same matter in the living organism we are faced with the phenomena of energy systems which do not degrade in linear succession but which are re-creative and perpetual. Considered in its parts, the living organism can frequently be explained with some success, but considered as a whole, the living organism can not. The non-living thing considered as a whole is merely the sum-total

of its parts, but the living thing is not, and as long as this difference exists, so long will it limit any physico-chemical explanation which the biologist can offer. The legitimate behaviourist realizes that this limitation exists; he knows that complete explanation must include not only the results of the labours of the chemist and physicist but also those of the psychologist and the metaphysician. Thought, mind, psyche or whatever else it may be called, is as much a phenomenon of living matter as its mass, its molecular constitution and its re-creative property. Some day, no doubt, a synthesis of these varied bodies of knowledge will be achieved, but for the present the true Behaviourist will content himself with description rather than explanation, and will adopt that most difficult of all views, a truly agnostic attitude, towards the dogmas of the materialist and mechanistic schools. If he does so, biology will certainly be under a very great debt to the Behaviourist, and not as at present, only rather mystified by terminologies which have no meaning and by explanations which explain nothing and carry no conviction.

THE CHROMOSOME BASIS OF SEX DETERMINATION.

By KATHLEEN B BLACKBURN, D.Sc., F.L.S.

All living organisms are made up of units called cells. A cell consists of a fundamental chemical complex called protoplasm of which the most important part is a central body, the nucleus. Increase in size is largely due to multiplication of these cells.

When a cell is about to divide to form two the nucleus first divides and, in so doing, shows itself to contain a number of highly stainable bodies, the chromosomes. At the nuclear division each of these is accurately halved so that every nucleus contains exactly the same number of chromosomes, and the number is constant for any individual type of organism, for instance in a rat the number is always 32.

Now in the higher organisms reproduction is brought about by the fusion of a male with a female cell. By a process termed the "reduction division" (during which the chromosomes, instead of each dividing into two, as above, separate into two equal groups, each of which forms a new nucleus), the chromosomes of the sexual cells are half the normal number characteristic of the organism: the fusion of male and female cells restoring the original number.

These bodies, the chromosomes, are practically the only constant feature of the sexual cells and are consequently of very great importance in the handing on of hereditary characters. Thus at the reduction division the opportunity occurs for the sorting out of the parental characters.

Now among the characters with which offspring are endowed is that of sex; the method of determination of which has always been a matter of great interest.

It has long been known that in bees an unfertilized egg produces a drone, whereas a worker, or queen, is produced

by fertilisation, whereby the drone possesses half the chromosome number of the female. A rather less obvious, but quite as definite, difference is found in many cases of animals in which the female has one more chromosome than the male; in this case the male has always an uneven number of chromosomes: take for example the bug, *Anasa tristis*, the male animal has 21 chromosomes whereas the female has 22. Thus in the case of the female, the chromosomes being exactly divisible by two the result will be that the eggs will all be alike, with 11 chromosomes each, whereas the male cells or sperms will contain either 10 or 11 chromosomes. The 10 chromosomed sperm fusing with any egg will produce a 21 chromosomed individual, a male, but in the case of the 11 chromosomed one the result will be a 22 chromosomed female. In these cases it is obviously the nature of the sperm which determines the sex of the offspring. From this it will be seen that the odd chromosome in the male corresponds to a pair of similar ones in the female: these are termed the sex or X chromosomes.

In a slight modification of this type, instead of lacking one altogether, the X chromosome in the mule has a small partner called the Y chromosome, but this makes no material difference to the simple method of sorting out the sexes as outlined above.

The majority of *animals* show some method of this sort for determining sex, but in *plants* the state of affairs is different in most cases, because one individual bears both male and female organs, so, no sorting out mechanism is required. There are, however, numerous cases in which plants, like animals, are definite male and female individuals, as for example, willows, hops, sorrel, Canadian waterweed and the red and white campions. Naturally, Botanists have been searching for sex chromosomes in such plants for many years, but it was not until 1923 that success rewarded their efforts, they were then found at almost the same time by four independent workers.

Among these discoveries the results of my own work on the red and the white campion and the hybrid between

the two (*Lychus divaricata* agg.) are perhaps the most straightforward and clearly marked. On investigating the female plant I found that it has 12 pairs of chromosomes of which the individuals of one pair are distinctly larger than those of the others. The egg cells are all exactly alike, having 11 small chromosomes and one large. The male plants have also 24 chromosomes but I found that the large pair is most obviously composed of unequal elements, the smaller of which corresponds in size to those of the female and is thus the X element; the larger one is the Y chromosome, thus reversing the usual arrangement in animals.

The mechanism here is, however, astonishingly like that in animals; and, since in this case all the evidence points to the condition being a relatively recent acquisition, it seems likely that there is something more fundamental about it than would at first sight seem probable.

One of the best pieces of evidence as to the soundness of this hypothesis of the method of sex determination is ease with which it explains the peculiar inheritance of certain defects, notably colour blindness in man and the occurrence of the narrow leaved form of the white campion. If, for instance, a colour blind man is married to a normal woman, the children will all be normal. The sons will not hand on the defect to their descendants, but the case of the daughters is different. Half of the sons borne by these daughters will be normal, half colour blind. Their sisters on the other hand will be normal, but half of them will be capable of passing on the defect. Now if you assume that the colour blindness was due to a defect in the X chromosome of the original colour blind father it is obvious that only half of his children can inherit it, these will be the females but, since in the females there is a pair of X chromosomes, one of which will be normal, the effect does not appear. Half of her children will, however, carry the abnormal chromosome and the defect will then appear or not according to the sex.

To return to the actual question of sex inheritance, it will be obvious that, theoretically, the two sexes should

occur in equal numbers but actually they do not. The champions, on which I have worked, are most conspicuous examples of this discrepancy; in some races the disproportion is extreme and would appear to be particularly great in experimental families. Some very careful and ingenious experiments made by Correns in Berlin have thrown much light on this case. He has shown that the average speed of growth of the pollen tube is greater in female determining pollen grains than in the male determiners. Thus if a large excess of pollen reaches the stigma the proportion of female plants is likely to be greater than if the number of pollen grains corresponds more nearly to the number of ovules to be fertilized.

From this it will be seen that, usually, the sex of an organism is determined at the moment of its inception, i.e., at fertilization, but which male cell succeeds in effecting fertilization may be governed by other factors than blind chance and may occasionally be capable of external control.

LIST OF PAPERS READ DURING THE SESSION

1923

- Nov 16th Notes on Physical Deformations By Prof T H Havelock
- Dec 3rd The Resistance of Air to moving bodies and some recent experiments By R C Iunn MA
The theory of the Neon Lamp By J Taylor B Sc
- 13th The Intelligent explanation in Biology By Dr B M Griffiths
- 17th The estimation of laevoglucose in Plant Tissues By S H Collins M Sc
A method of determining the composition of solid solutions By W M Milligan

1924

- Jan 21st Application of the Farnsworth Valve to the measurement of Physical Constants By J A Sayce B Sc
The Oxidizing structure of the Sugars By S Baker B Sc
Tropinone Condensations By J M Smith B Sc
- Feb 8th A Discussion on Plant Sugars opened by Mr S H Collins
- 20th The Differential Equations of Meteorology By L F Richardson
The Present position of X-ray Crystal Analysis By J F Wood M Sc
- , 28th — Coal-tar appliances at the Tyne Improvement Commissioners Works By F G Wilson
- , 29th A simple infinite product By J L Burchall MA
- , The Limits of Stability in Satellite Orbits By Dr G R Goldsbrough
- Mar 4th — Some experiments on Electro physiology By Prof M C Pitter
- , The Chromosome Basis of Sex Determination By Miss K D Blackburn
- 17th — Heredity in Man By Dr J W H Harrison

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THE FORCE BETWEEN TWO MAGNETISED SPHERES.

By G. W. BRYDON, B.Sc., A. ELLIOTT, B.Sc., and
R. G. LUNNON, M.A., M.Sc.

This paper is concerned with the measurement of the force of repulsion between two equal steel spheres placed in a field of magnetic force, the direction of which is perpendicular to the line of centres. The theoretical calculation of this force is not yet possible, and it does not seem to have been measured hitherto.

PART I.—PRACTICAL.

First Method.

In some experiments described by L. V. King* the forces of repulsion between magnetised spheres were displayed by setting the spheres on a concave watch-glass. The various patterns made by different numbers of spheres in their positions of equilibrium are admirably suggestive of the electron groupings in a model atom. We first applied this principle, using two spheres only, to determine the relation between the force, which we shall call F , and the distance, to be denoted by r .

A circular coil of 20 cms. mean diameter was laid horizontally, and a concave lens of spherical surface was supported centrally within it. Steel balls of $\frac{1}{8}$ inch diameter were placed on the lens; and when alternating currents of about two amperes were passed through the coil, the balls flew apart until their mutual repulsion was just equal to their tendency to roll down the lens. The

* King, *Phil Mag.*, 44 (1923), 395.

distance between them was then measured by a travelling microscope, setting the cross-wire on both inner and outer edges of each sphere. From this distance and the radius of curvature of the lens, the force was calculated from the formula

$$F = \frac{mqr}{\sqrt{4(a-b)^2 - r^2}}$$

which is easily derived. Here m is the mass of each sphere, a is the radius of the lens surface, b the radius of each sphere. Six different surfaces were used, and six different values of the current with each surface.

The results are best shown by plotting $\log F$ against $\log r$, and these curves are shown in Fig. 1. They can be very well represented by straight lines, and if the slope of these lines is n they correspond to the law of force:

$$F = kr^n.$$

The numerical values are as follows:—

Current	n	k
1.00 amps	3.51	0.18
1.40	3.54	0.38
1.82	3.81	0.63
2.07	3.84	0.74
2.29	3.65	1.05
2.68	3.64	1.38

Radius of curvature of the lenses: 2.85, 4.3, 6.9, 10.95, 21.3, 32.6 cms.

Distances between the spheres: from 0.3 cms. to 0.8 cms.

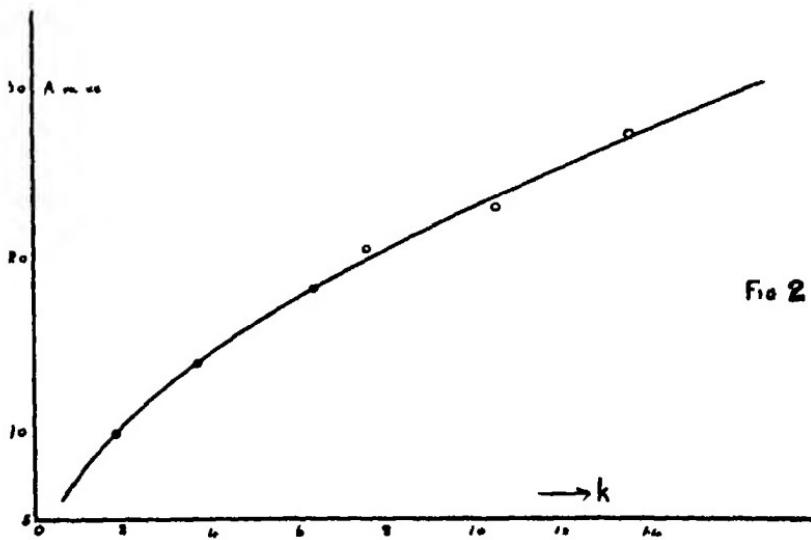
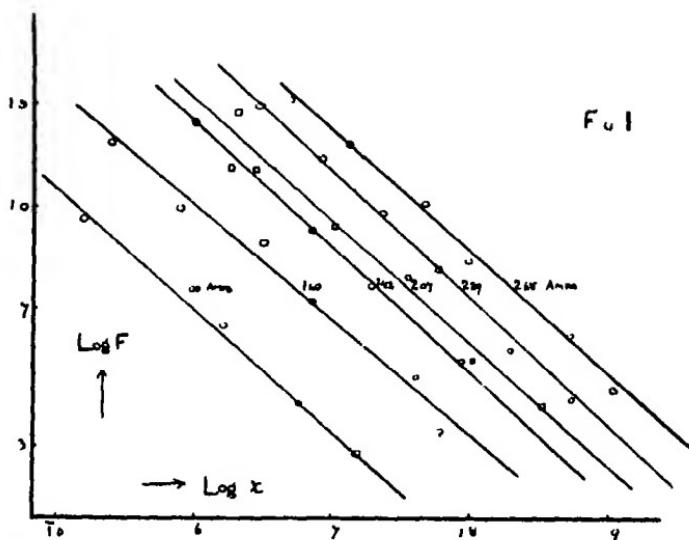
Diameter of sphere—0.312 cms.

Mass of sphere = 0.125 gram.

Magnetic field strength—40 100 gauss.

Mean value of n — 3.66 ± 0.10 .

The theory indicates that the factor k should be proportional to the square of the magnetic force and hence to that also of the current. The relation between the observed values of k and the current is compared in Fig. 2 with this theoretical result, and is found to agree with it: the experimental points lie fairly well upon the theoretical parabola.



Second Method

From these first results it was evident that it would be valuable to measure the force by a more accurate method, in which possible surface defects in the spheres and in a lens surface had no disturbing effect. A convenient torsion balance was therefore constructed. This consisted of a light horizontal glass arm, 80 cms. long, carrying a steel sphere at one end, and supported by a fine wire, at first of copper and later of phosphor bronze, 20 cms. long. The arm carried also a mirror, for use with a lamp and scale, and a damping vane immersed in a dash-pot containing water. The upper end of the torsion wire was fixed to a graduated screw-head, and to this, another mirror was attached, to permit of greater accuracy of reading. The whole was enclosed in an air tight box and its final sensitiveness was such that a deflection of 1 mm. on the scale was produced by a force of 7.9×10^{-5} dynes acting on the ball. The actual forces measured were between 0.005 and 0.25 dynes. The torsion constant was measured in the usual way, by timing the oscillations of the beam before and after attaching a standard inertia bar.

The second steel ball was mounted on a metal strip attached to the case in such a way that its position could be altered in two directions by means of two adjusting screws. In every experiment the two balls were first just brought into contact by turning the torsion head, then the current was switched on, and the position of the ball was determined for each of a series of positions of the torsion head.

In these experiments, especial care was taken to see that the magnetic field was exactly vertical and uniform throughout the area containing the balls. Two horizontal coaxial coils were mounted so that the balls were in a plane midway between them, and this gave a very uniform field.

In some experiments where a non-uniform field was used, its effect was examined by removing the fixed ball, and measuring the force upon the movable one in various

positions. This force was subtracted from the values obtained when the fixed ball was replaced. This extra force was due to the tendency of the steel to move into the strongest part of the field. There might also have been a slight difference in its amount according to whether direct or alternating current was used, depending upon the hysteresis energy losses: this was carefully examined, and no measurable effect was found. The balls were demagnetised after each experiment.

Four sets of readings were taken, with different currents, different pairs of coils, and different suspension wires. They are shown in Fig. 3 as four curves connecting the logarithms of force and distance; and each of them is again a good straight line. Their slopes are 3.41, 3.50, 3.86, 4.05, and the mean of these numbers, 3.70, is very near to the value obtained (3.66) in the first method of measurement. The distances were between 0.5 and 1.8 cms., *i.e.*, from two to six diameters of the sphere, and the magnetic fields were of the order 100 gauss. The law of force is, therefore, within this range, well expressed by the relation :

$$F = kx^{-3.7}$$

PART II.—THEORETICAL..

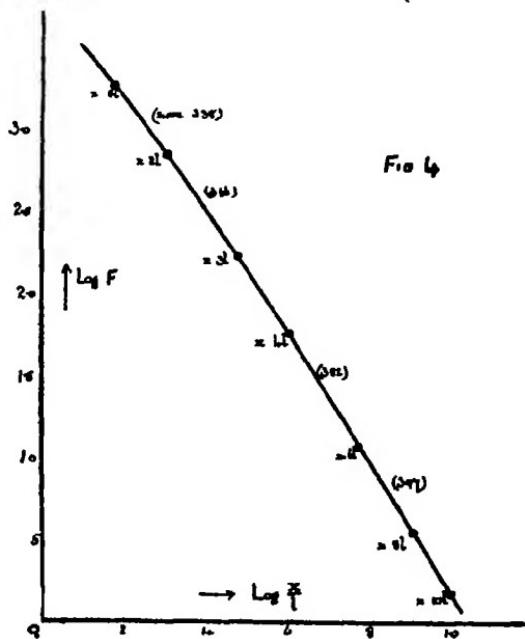
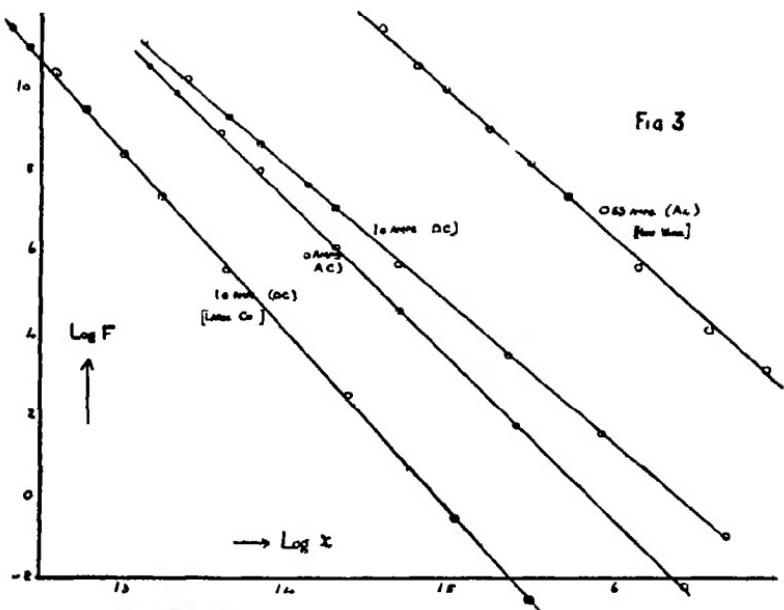
The problem is immediately soluble when the relative dimensions are such that the influence of the field on one sphere may be treated as being independent of the presence of the other sphere. In this case, the magnetic moment of each sphere is given by

$$M = 2ml - \frac{\mu - 1}{\mu + \frac{1}{2}} \cdot H \cdot a^8 \quad (1)$$

where μ is the permeability of the material, a the sphere radius, and H the field strength. The force is given by

$$F = 2m^2 \left(\frac{1}{a^8} - \frac{x}{(x^8 + \bar{m}^8)^{\frac{1}{2}}} \right) \quad (2)$$

It is interesting to compare this expression with the simple power law we have derived from experimental results, and



a graph of $\log F$ with $\log x/l$, calculated from (2), is given in Fig. 4. Evidently if the convenient but unreal quantity l can be treated as a constant, we may write

$$F = kx^*$$

for any limited range of x , and the value of n rises from 3 to 4. But the experimental graphs, though differing in slope, are each of them straight lines of unvarying slope, and the formulae based on a constant l term are therefore inaccurate.

A next approximation can be made by considering the field in which each sphere stands to be reduced in value from H to

$$H - \frac{\mu - 1}{\mu + 2} \cdot \frac{a^3}{x^3} \cdot H$$

by the presence of the second sphere. This leads to an expression :

$$F = \frac{a^3}{2r^3} H^2 \left(1 - \frac{a^3}{x^3} \right)^2 \left(\frac{1}{x^2} - \frac{x}{(x^2 + r^2)} \right)$$

and this involves a rather slower increase of n with increasing r than the former expression.

Further results can only be obtained by pursuing the tedious method of images. A formal statement of the solution by this method has been given by Boggio,* but the actual result has not been obtained.

An alternative line of attack upon the problem is to apply the toroidal coordinate systems developed by Hicks and Jeffery.† We take curvilinear coordinates u , v , w , such that $u = \text{const.}$ is a series of coaxal spheres, two of which are the given spheres, $v = \text{const.}$ is a series of spheres through the limiting points, and w measures angles about the z axis. Then the undisturbed potential, V_0 , is expanded in a suitable form without much difficulty :

$$V_0 = -2\sqrt{2aH} \sqrt{\cosh u - \cos v} \cos w \sum_1^\infty (n+1) P_n(\cos v).$$

* Boggio, *Rend. del r. Inst. Lomb.*, 37 (1904), p. 405.

† Jeffery, *Proc. Roy. Soc., A.* 87 (1912), p. 100.

A similar series with unknown coefficients A_n , B_n is next assumed for the disturbed potential, and the boundary conditions (V and $\mu_{\delta u}^{\delta v}$ both continuous) are applied to determine A and B . This leads to a difference equation :

$$\begin{aligned}\mu \left[\left((n+1)A_n - (n+2)A_{n+1} \right) e^{-(n+\frac{1}{2})a} + \left(nA_n - (n-1)A_{n-1} \right) e^{-(n-\frac{1}{2})a} \right] \\ = - \sinh a \cdot e^{-(n+\frac{1}{2})a} + \left[(\overline{n+1}B_n - \overline{n+2}B_{n+1}) \cosh n + \frac{3}{4}a \right. \\ \left. + (nB_n - n-1B_{n-1}) \cosh n - \frac{1}{4}a \right]\end{aligned}$$

which is at present insoluble.

At present, therefore, only the experimental conclusion is available and it is of a simpler form than had been anticipated, viz. :—

For distances apart of from 2 to 10 times the diameters, the force between the two spheres is given by

$$F = k \cdot H^2 e^{-3/7}$$

THE PHOTO-ACTIVATION OF CHLORINE.*

By WILFRED TAYLOR, B.Sc., RESEARCH SCHOLAR, ARMSTRONG COLLEGE.

The original classification of photo-chemical reactions by J. Stark admits of the following possibilities:—

- (1) Where the light releases photo electrons.
- (2) Where the light induces electrically neutral dissociation.
- (3) Where the radiation acts by its heating effect.

In addition to these, however, we must recognise other cases, and recent work seems to indicate that the old theory of activated molecules, first propounded by Arrhenius, may serve to explain these exceptions. Recent work has shown that it is possible to have profound internal molecular changes which yet leave the molecule, as a whole, electrically neutral. These changes are brought about by the absorption and emission of energy; the energy generally appears in the radiant form with definite frequencies forming the absorption and emission bands of the characteristic spectrum. Full details are given in Sommerfeld's "Atomic Structure and Spectral Lines," also in the papers by Curtis (*Proc. Roy. Soc.*, A 101, 38, 1922), and V. Henri (*Proc. Roy. Soc.*, A 105, 662, 1924).

It is shown in the above works that a normal molecule may absorb energy from an incident beam of radiation, and pass into a new and less stable configuration, the valency electron being thrown into higher quantum orbits. We may speak of this new state as being an "activated condition"; Sir J. J. Thompson has put forward the theory that in a condition of such intra-molecular strain the molecule is able to enter into chemical reactions previously excluded.

* This research forms the subject of a note in the *Phil. Mag.*, 49, 1165, 1924.

The object of the present research being to study the physical results of such preliminary activation, a genuine example of this kind was sought among the large number of known photochemical reactants and the very well investigated behaviour of chlorine seemed to promise a suitable subject of investigation. Under the influence of light the chemical properties of chlorine are greatly modified and it reacts with benzene carbon monoxide and with hydrogen itself to form hydrogen chloride. This last reaction has been very carefully studied by chemists and has provided a very extensive literature. The fact that a moist mixture of equal proportions of hydrogen and chlorine although quite stable in the dark unites to form HCl on exposure to light was known by Davy and first studied by Draper who came to the conclusion that the light increased the electro negative properties of the chlorine. Draper's work was repeated by Bunsen and Roscoe using an improved form of actinometer and later by Burgess and Chapman (see *Proc Chem Soc* 20 164 1904 and *J C S* 89 II 1399 1906).

That the reaction does not come into any of Stark's categories seems to be shown by the fact that no trace of the presence of ions during the combination could be found by Sir J J Thompson (*Proc Camb Phil Soc*, 11 90, 1901) Lenard and others that there is no change in the relative densities of illuminated and dark chlorine (Kummell & Wobig *Zent Elektrochem*, 15 252, 1909, and 17 409 1911) and that filtering the light from heat rays does not alter its effect. The return of the molecules from the activated to the normal state is almost instantaneous since it has been shown that the activity ceases immediately on cutting off the light (Bovie *J A C S*, 37 1721, and Wendt, *J A C S* 44 2377).

For the purpose of the physical investigations it was, however necessary to define precisely the spectral limits (if any) of the activating light and here, little trace could be found in the literature of the subject of any precise determinations. It has been stated that cutting out blue and red light produces little change, and again the

Grotthus law of photo-chemistry has been invoked, whereby only that light actually absorbed by the gases is effective in promoting the reaction, but the absorption spectrum of chlorine is complex and comprises both band and fine line systems extending over most of the visible region. It was hence desirable that actual determinations should be made.

The chief obstacle previously in the way of such work has been the difficulty of obtaining sufficiently strong monochromatic radiations suitably placed throughout the spectrum. In the present case, a set of very perfect colour filters designed by Sir Wm. Pope was employed. Each filter passed a narrow band from some portion of the spectrum and no extraneous visible radiation whatever. The complete set of eight filters covered the whole visible region. The apparatus constructed was a modification of the actinometer of Burgess and Chapman (*loc. cit.*), consisting of a bulb of 50 c.c. capacity fitted with inlet and outlet tubes and a graded capillary tube along which an index (of sulphuric acid) could move freely and indicate contractions of volume of gas in the bulb. The floor of the bulb contained pure water saturated with chlorine and hydrogen. The gas mixture was supplied by the electrolysis of pure concentrated hydrochloric acid in all-glass communication with the bulb inlet. Electrolytic gas prepared in this way is contaminated with oxygen, the quantity varying in a complex way with the concentration of the acid, but the subject had previously been investigated by Chapman (*J. A. S.*, 95, 135 and 959), and the knowledge so obtained was utilised to reduce this difficulty to a minimum. The stopcocks were all lubricated with syrupy phosphoric acid instead of ordinary grease.

The bulb was sunk in a large water bath fitted with an air thermometer, and encased in an opaque cover having a small window and shutter. The room itself could be completely darkened in addition.

The illuminating beam was provided by the light from a "Pointolite" electric lamp of great brilliancy, having a

point source and practically no heat radiation. This light was collected by means of lens system and brought to a focus after passing through a water cell. The focus fell in the plane of a slit in a screen at which place the colour filters could be placed. The beam then diverged and passing through the window of the water bath fell upon the bulb.

The chief experimental difficulty lay in the peculiar action of the inhibiting agents whose influence has been so fully traced by Burgess and Chapman. At first exposures under identical conditions yielded reaction velocities varying by several hundred per cent and it was never possible to charge the bulb without introducing more inhibitor (presumably oxygen). The trouble was finally overcome by carefully standardising the filling operations by prolonged sluicing with gas mixture and by taking advantage of the fact that white light itself will remove the impurities after periods of inertness and induction. Accordingly before each set of exposures the bulb was exposed to white light until reaction began and then darkened until equilibrium was established again. The reaction when commenced with a colour filter in position proceeded with remarkable steadiness and volume/time graphs were straight lines to a high degree of accuracy so that the reaction velocities could be determined as the tangents of the gradients. All the readings were repeatable and as an additional precaution a second actinometer was constructed with some improvements suggested by experience obtained with the first and the whole set of experiments repeated again.

The results were quite definite. No action at all was obtained with any of the filters throughout the red yellow green regions but combination was initiated with the blue and violet. It might be remarked that any variation in the activating power was due to a difference in total intensity transmitted by the filters and to guard against this source of error the relative energies (after careful heat filtrations by water cells) were determined by a delicate thermopile arranged in the usual way with a Kelvin mirror.

galvanometer. The final results are given in the annexed table (reproduced from the *Philosophical Magazine*).

Filter	Reaction Velocity	Range of Wave lengths (Angstrom Units)	Relative Light Intensity	Corrected Activating Power
Violet	100	4300—4800	7	100
Blue	27	4550—5000	11	17
Blue green	14	4780 5370	13	8
Green	0	5050- 5570	15	0

The wave lengths were measured in a Hilger direct-reading spectrometer, and are, of course, only approximate since the band edge shaded off in a nebulous manner. Sufficient data were established by the above investigation to limit the activating portion of the spectrum and to show which wave lengths could be used in optical studies and yet leave the chlorine in the normal molecular condition. Such optical work is being at present proceeded with.

APPLICATION OF THE METHOD OF THERMAL ANALYSIS TO DETERMINE QUINQUEVALENCE IN AROMATIC ARSENICALS

By STANLEY PEAT

Tertiary arsines and bismuthines readily form organic derivatives in which the metalloid is pentavalent. The stability of these compounds appears to decrease progressively in passing from arsenic to bismuth, for the triarylarsines give rise to triaryalkylarsonium halides on warming, the arsine with the lower allyl halides, stibonium compounds being obtained using mixed allyl allyl iodides while the corresponding bismuthonium derivatives have not yet been isolated although compounds exist of the type BiR_2X_2 where R represents an allyl group and X a halogen. Indications of intermediate formation of bismuthonium compounds have been observed however by Challenger (*J.C.S.* 1914 **10**, 2211) who found that on heating isobutyl bromide with triphenylbismuthine diphenyl bromide bismuthine was produced.

In view of the greater stability of quinquevalent arsenic compounds it was considered that a diagram showing the variation of freezing point with composition of binary mixtures of symmetrical triarylarsines and aryl halides would show evidence of the formation of the arsonium addition product. It was hoped to extend this method of investigation to analogous compounds of antimony and bismuth in order to study on a comparative basis the valency of these elements.

To avoid experimental difficulties it was desirable to choose components which were solid and in addition to avoid subsidiary reactions it was necessary that the radicle attached to arsenic should be identical with that in the arylhalide. With this object in view quantities of tri-p-tolylarsine and p i o d o t o l u e n e have been prepared and an equilibrium diagram of the binary mixture examined.

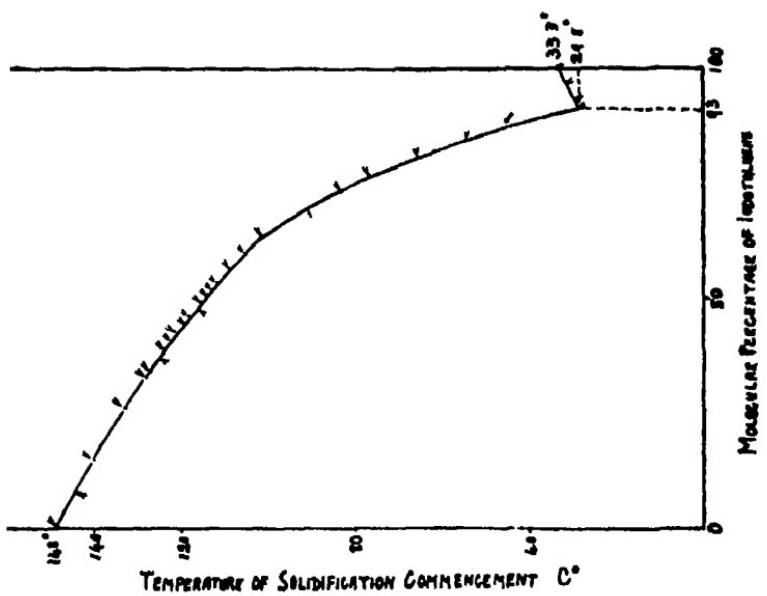


FIG. 2

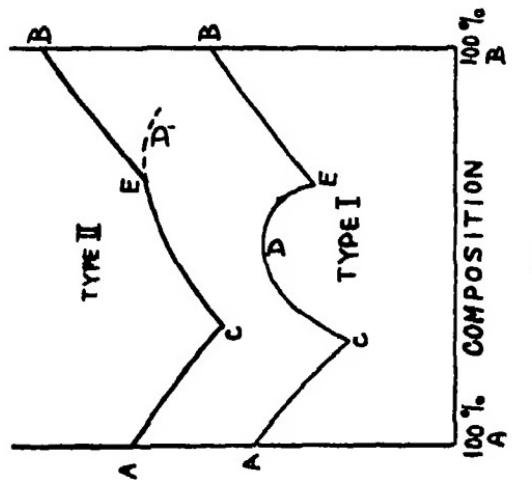


FIG. 1

Equilibrium Diagrams.

Equilibrium diagrams showing the variation of freezing point with composition in binary mixtures have been fully studied and described by Roozeboom (*Zeit. Physikal. Chem.*, 1899, 28, 505).

The complete freezing point curves should belong to one of the two types shown in Fig. 1 provided that the substances do form compounds and not mixed crystals.

These two types of diagrams show composition plotted on the abscissæ and corresponding freezing points on the ordinates.

In Type I. AC and EB represent the ordinary freezing point curves with eutectic points at C and E. The intervening curve CE contains a maximum point at D indicating the formation of a compound of the composition represented by D and, moreover, the compound is stable and has a definite melting point.

In Type II. the only difference is in regard to the intervening curve CE which does not show a maximum point except in the metastable region, shown by the dotted curve at D_1 .

The point D_1 indicates the melting point of a compound which is unable to exist in contact with solution at this temperature and therefore decomposes, at some lower temperature. The point E thus represents the limit of existence of the compound.

The two types of diagrams have been realised experimentally (Philip, *Journal Chem. Soc.*, 1903, 83, 821). Type I. is exemplified by phenol and α -naphthylamine and Type II. by mixtures of benzene in picric acid, these two compounds being represented by the points A and B respectively in Fig. 1. Philip also shows that the compound, containing equimolar proportions of benzene and picric acid is only stable when in contact with solutions containing excess of benzene, that is, at temperatures below the melting point.

EXPERIMENTAL.

Preparation of Materials.

(a) Tri-p-tolylarsine was obtained by the method of Michaelis (Ann. 1902, 321, 201), and also by means of the Grignard reaction using magnesium p-tolyl bromide and arsenious chloride. The latter method does not appear to have been previously described, but is not as satisfactory as the former, owing to the quantity of bye-products produced.

The specimen was recrystallised several times from alcohol benzene until the melting point was constant at 146 degrees.

(b) P-iodotoluene was prepared in the usual manner from p-toluidine and recrystallised from alcohol until the melting point was unchanged on further recrystallisation. All traces of solvent were removed by keeping in a high vacuum. It melted at 34° C. which is lower than the figure usually recorded (35° C.).

To obtain a diagram for the system p-iodotoluene and tri-p-tolylarsine a series of freezing points was determined for the pure substances and various synthetic mixtures.

The freezing points were determined by the cooling curve method, fusing the mixture (or pure substance) in a test-tube, heated in an oil bath. The test-tube was surrounded by a larger tube to provide an annular air space, and a thermometer passing through a cork in the mouth of the inner tube, was placed so that the bulb was completely immersed in the melt. A mercury-in-glass thermometer with a range 0°-175° C. graduated to 0.2° direct reading, was used for the determinations.

During cooling, the melts were stirred continuously with a glass stirrer.

The results are plotted in the curve shown (Fig. 2).

The curve shown represents a eutectic system with a eutectic mixture composed of 77 molecular percentage of tri-p-tolylarsine thus giving one branch curve much longer than the other. This longer branch curve shows marked curvature but no evidence of compound formation.

In order to decide whether or no a higher eutectic point did exist (see E, Fig. 1, Type II.), a set of complete cooling curves was obtained for mixtures on the pure tri-p-tolylarsine side of the diagram.

Cooling curves for eutectic systems are of the form shown in Fig. 3A.

B is the temperature at which solid first separates and is therefore the freezing point of the given solution.

CD represents a constant temperature period corresponding to the separation of eutectic mixture and generally referred to as the "eutectic time."

Such a period should be shown for every eutectic point which occurs.

On examining a large number of cooling curves, covering a wide range of compositions, it was found that only one eutectic point, at a temperature of 29° C. occurred.

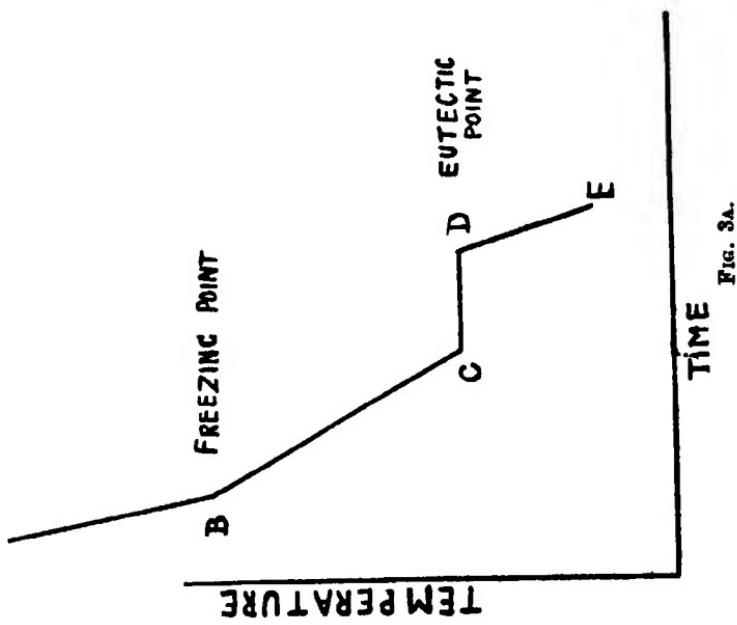
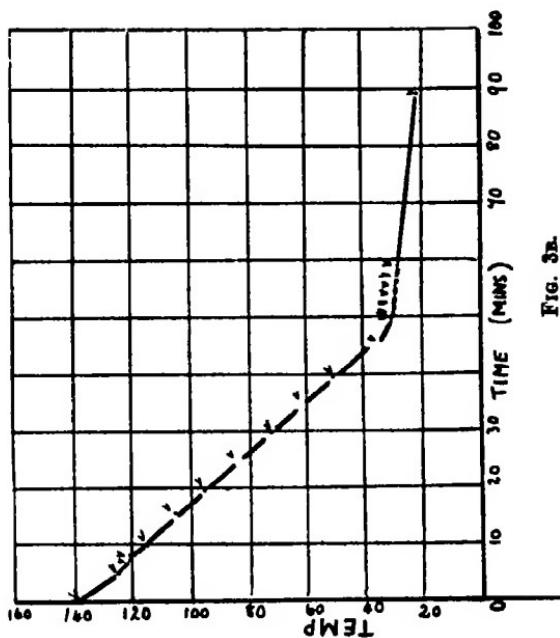
A typical cooling curve for a mixture containing 55 molecular percentage of tri-p-tolylarsine is shown in Fig. 3B. The "eutectic time" is at 29° C.

Conclusions.

The diagram (Fig. 2) obtained does not show any evidence of compound formation between the two components for an ordinary eutectic diagram represents the conditions of equilibrium.

Owing to the relatively high stability of arsenic compounds it is not to be supposed that stibonium or bismuthonium compounds would be formed under similar conditions.

The fact that tri-p-tolylmethylarsonium iodide is readily formed from its generators, while tetra-p-tolylarsonium iodide is not produced under similar conditions would appear to be due to the negative influence of the aryl



group. A further example of this nature has been given by Gruttner and Wiernik (Ber. 1915, 48, 1760) who find that dimethylphenylstibine adds on methyl iodide while methyldiphenylstibine does not, the replacement of one alkyl by an aryl group being sufficient to prevent combination.

The behaviour of the intermediate aliphatic-aromatic radicle, benzyl, is similar to that of alkyl, pentavalent compounds, compounds such as tri-m-tolylbenzylarsonium chloride being easily prepared.

The equilibrium curve obtained, shows, however, that under the above conditions there is no indication of the formation of an additive compound, and it appears probable that no tetra arylarsonium derivatives can be prepared.

In conclusion the author wishes to acknowledge his indebtedness to Messrs C. F. Allpress and W. M. Madgin, for their assistance and guidance.

THE EXPERIMENTAL DETERMINATION OF THE DISTRIBUTION OF STRESS ACROSS THE WALLS OF THICK CYLINDERS SUBJECTED TO INTERNAL PRESSURES.

By H. E. LANCE MARTIN, B.Sc., Assoc M Inst C.E

Rarely has a theory with so little experimental evidence been used in practical design as Lamé's theorem dealing with stress distribution across the walls of thick cylinders. The difficulties of measurement have, no doubt, greatly contributed to this; as it has not, in the past, been possible for direct stress measurements to be made on the same cylinder. Strain measurements* have been made at the outer radius from which the stress has been deduced, but this information, valuable as it is, does not yield the actual distribution of stress from point to point across the walls.

The present article deals with the latter problem and compares the experimental results with Lamé's theorem.
Statement of the Theorem of Lamé.

In Fig. 1 let p be the radial compressive stress (+) at any radius r , and q be the resulting circumferential tensile stress (-). Then considering the equilibrium of the element $abcd$ of a cylinder of length l , the algebraic sum of the horizontal and vertical forces must be zero. Hence,

$$l(p + dp)(r + dr)d\theta,$$

added to the two vertical components of

$$l.q.dr, \text{ viz } 2.l.q.dr.d\theta/2$$

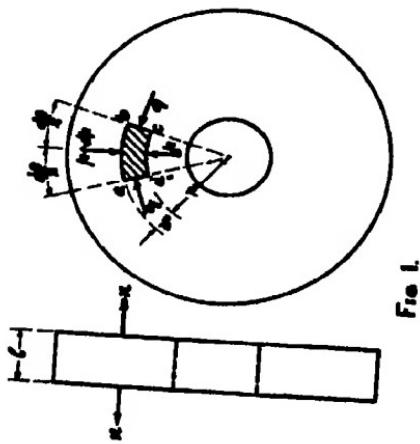
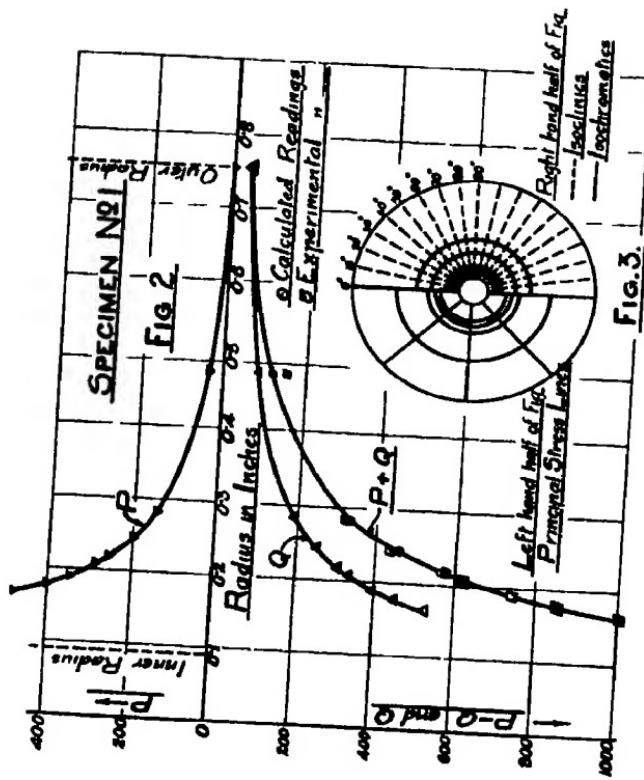
must balance $l.p.r.d\theta$ or

$$l(p + dp)(r + dr)d\theta - l.q.dr.d\theta - l.p.r.d\theta = 0$$

Dividing through by $l.d\theta$ and neglecting the product of small quantities

$$p + r.dp/dr = q \quad . \quad . \quad . \quad (1)$$

* "Strength of Thick Cylinders under Internal Pressure," by G. Cook, M.Sc., Assoc.M.Inst.C.E., and A. Robinson, M.Sc., Engineering, 15th Dec., 1911.



The horizontal forces, $q \cdot m \cdot \cos(d\theta/2)$ are equal and opposite and thus cancel each other.

Equation (1) is true statically, but is indeterminate for the solution of the stresses by itself. A further equation is required and is supplied by the assumption, which Lamé makes, viz., that the longitudinal strain on a plane section of a long thick cylinder is constant when subjected to internal pressure, the section being a considerable distance from the ends; in other words, it is assumed that the section remains plane after loading. Moreover, the ends may be open or closed. If open, the strain is only due to the stresses p and q , but if closed, the longitudinal strain due to the uniform longitudinal stress n must be added. Taking the latter as being the slightly more general

$l \cdot n/E + l \cdot p/m \cdot E + l \cdot q/m \cdot E = \text{a constant}$, where m is Poisson's ratio and E is Young's Modulus of Elasticity
Dividing through by l/E ,

$$n + p/m + q/m = \text{a constant};$$

of these quantities n and m are themselves constant, therefore

$p + q$ must also be equal to a constant.

$$\text{Let } p + q = 2e,$$

substituting the value of q as given by equation (1) in (2)

$$2p + r dp/dr = 2e,$$

which, multiplied across by r and integrated, gives the well-known solution :—

$$p = e + b/r^2 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$q = e - b/r^2 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The theorem has been given at length in order to emphasise the assumption made for obtaining equation (2). In the present work the second relationship between p and q has been determined experimentally.

In practice it is undoubtedly true that the normal stress n is uniform for sections which lie at considerable distances from the ends of the cylinder. Advantage of this fact was taken to make n zero, and thus the specimen cylinders could have open ends, whilst the length l was made to convenient dimensions.

The specimens were made of "celluloid," approximately 0.17 inch in thickness, in the form of accurately turned discs with holes of different diameters drilled in them. Each disc was subjected to internal pressure and the resulting stress distributions were obtained by examining the specimens under plane polarised light, and using the "Wedge" method and the "Single Sheet" method.[†]

In order that the results of each experiment should be strictly comparable, the specimens were also allowed to remain loaded for approximately two days before the standard measurements were taken. Other tests were made, however, for the same loading, at shorter and longer periods of rest, so that the effect of time could be studied in detail. These tests will be discussed later, as it is of interest to show that the chosen period of two days lies on that part of the stress-time curve at which the majority of the lag has actually taken place.

Standard Tests.

The overall dimensions of the four specimens are detailed in Table I.

TABLE I

Number	External Diameter in inches	Internal Diameter in inches	Thickness in inches
1	1.5075	0.180	0.17
2	1.5040	0.280	0.17
3	1.5045	0.367	0.17
5	0.7390	0.180	0.17

Four radial measurements were taken across two diameters at right angles to each other, and the mean of these four measurements was adopted as the radius at which the stress-difference $p+q$ occurred. This method was found to be advisable on account of the "isochromatic" lines not being quite circular, either due to want of symmetry of loading or to slight differences in the material. See Fig. 3.

[†] "Some Further Properties of Celluloid with a Discussion on the Basic Principles of Optical Methods of measuring Stress and Strain," by the Author. *Proceedings of the University of Durham Phil. Society*, Vol. VI., Part 5.

Again, so that the numerical work should be reduced to a minimum the retardation corresponding to the stress-difference has been retained throughout. Had the stresses themselves been required they could have been evaluated by the method described in the paper to which reference has been made.

Table II. gives the results of one of the tests. In the first two columns are recorded the actual experimental figures; in the third column the calculated stress-differences from the discovered law. The discrepancies between the calculated and the experimental stresses, and the mean square residual for the whole test are given in the fourth and fifth columns respectively.

TABLE II
Specimen 1

Radius (Means of 4).	Experimental Stress-diff ($p + q$) ^a	Calculated Stress diff ($p + q$)	Residuals	M S R	R marks
0.7538	—	— 47.26	—	—	Tested 49 hours after loading.
0.4765	— 150	— 118.30	+32	—	
0.2836	— 320	— 334.10	14	—	
0.2436	— 470	— 452.00	+17	—	
0.2180	— 570	— 565.10	+5	± 19.2	The outer and inner diameters measured
0.2080	— 620	— 620.70	+1	—	1 hour after loading
0.1896	— 740	— 747.00	-7	—	1.308 inches and
0.1773	— 855	— 854.40	+1	—	0.1815 inch resp.
0.1633	— 1005	— 1007.00	2	—	

*Note—In Fig 1 “ q ” is shown as a compressive stress and equation (1) has its signs accordingly “ q ” is, however, tensile, hence the DIFFERENCE between “ p ” a positive compressive stress and “ q ” a negative compressive stress must be written as “ $p + q$ ”

After several preliminary trials the following equations were found to fit very closely the experimental data :—

Specimen 1. $p+q = -26.86/r^2$ with a M.S.R. of ± 19.2

Specimen 2. $p+q = -53.00/r^2$ with a M.S.R. of ± 15.4

Specimen 3. $p+q = -84.50/r^2$ with a M.S.R. of ± 19.0

Specimen 5. $p+q = -21.50/r^2$ with a M.S.R. of ± 26.0

Hence the stress-difference can be written in the general form :—

$$y+q \equiv -2b/r^2 \quad , \quad (5)$$

where b is a constant. The minus sign is used because the experimental stress-difference was found to be tensile.

Connecting this equation with the statically true statement of equation (1) we have:—

$$2p = -r dp/dr - 2b/r^2,$$

which on being integrated yields:—

$$q = a - b/r^2 \quad , \quad , \quad , \quad , \quad , \quad , \quad . \quad (7)$$

These results are identical with those given by Lamé's theorem for long thick cylinders, where a is a constant and is the same as e in the statement given above.

The numerical values of p and q and their sum $p+q$ are given in Table III, and Fig. 2 shows graphically these results together with the stress-differences. It will be seen that the experimental points lie very close to these curves.

TABLE III.

Specimen 1.

Radius (Means of 4)	Calculated Stream-diff $p+q$	p	q	$p-q$ (sum)	Alternate Method.		
					p	q	$p-q$ (sum)
0.7538	-47.26	0	-47.26	47.26	0	-47.26	-47.26
0.4765	-118.30	35.52	-82.78	47.26	39	-79.30	40.30
0.2836	-334.10	143.37	-190.73	-47.26	120	-194.10	-54.10
0.2430	-452.60	202.07	-249.93	-47.26	200	-252.60	-52.60
0.2180	-565.10	258.07	-306.13	-47.26	263	-299.00	-36.20
0.2080	-620.70	286.72	-333.98	-47.26	204	-327.00	-33.00
0.1898	-747.00	349.87	-397.13	-37.26	357	-390.00	-33.00
0.1773	-854.40	403.57	-450.83	-47.26	411	-444.00	-33.00
0.1633	-1007.00	479.87	-527.13	-47.26	484	-520.00	-36.00

As an independent check the experimental information that can be obtained from the "isoclinics" was compiled. From the images of the specimens as seen on the screen of the polariscope it was observed that these isoclinics were symmetrical radial straight lines, and consequently also lines of principal stress (Fig. 3). By the method due to Prof. L. N. G. Filon, M.A., D.Sc., F.R.S., as described by him in a contribution to the report of the Committee of

Section G of the British Association on Complex Stress Distribution, 1923,* this additional experimental evidence was also used to obtain the values of the stresses p and q .

Under the heading of Alternate Method in Table III. the values of the stresses so obtained are given. They compare favourably with those previously determined, the variations being primarily due to the unavoidable inaccuracies of graphical integration.

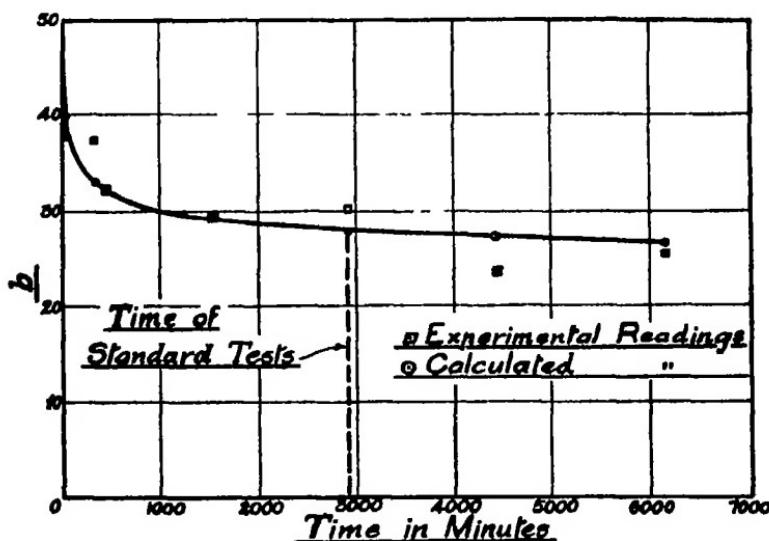


FIG. 4.

The Effect of Time.

The plan adopted to investigate the effect of time was as follows. Radial measurements across a single diameter of Specimen 1 were made at convenient periods of rest. The probable value of the constant b for each period was then calculated and these values were plotted against the time. The equation to this curve was then determined and the probable values of the constants contained in it were estimated. The equation found was:—

$$b = 50/t^{0.0728},$$

* See *Engineering*, 19th October, 1923

or putting it in the general form

$$b = A/t^n \quad \quad (9)$$

where A and n are constants and t the time interval in minutes reckoned from the time of loading. It will be seen in Fig. 4 that for the periods adopted in the four standard tests, the values of b are approaching uniformity.

The index of t , which was derived from measurements taken across a single diameter, was used when applying equation (9) to the four standard tests, although the latter had their measurements taken across two diameters at right angles to each other. Table IV. gives a summary of this work.

TABLE IV

Specimen	A	t in min.	Experimental "b"	Calculated "b"	Remarks.
1	47.0	1,545	27.6	26.86	Each value of "b" was obtained from the mean of four radial measurements taken across two diameters at right angles to each other.
	47.0	2,920	26.4		
2	94.7	60	70.42	—	
	94.7	2,960	53.00		
3	143.0	210	97.00	80.50	
	143.0	2,880	83.50		
5	37.6	60	28.00	21.4	
	37.6	2,940	21.3		

Method of Co-ordinating the data obtained from the Standard Tests.

To demonstrate that the data obtained from the four principal experiments are strictly comparable, it is convenient to plot the ratio $p/p+q$ against the ratio w/d where w is the width of the material between the outer radius and the radius r at which the stress-difference $p+q$ occurs; and d is equal to $2r$. See Fig. 5. The values of these ratios, given in Table V., are shown plotted in Fig. 6, where it will be seen that the points from all the tests lie on a curve. It follows therefore that the general law:—

$$p+q = -2b/r^2,$$

is equally true for the four tests.

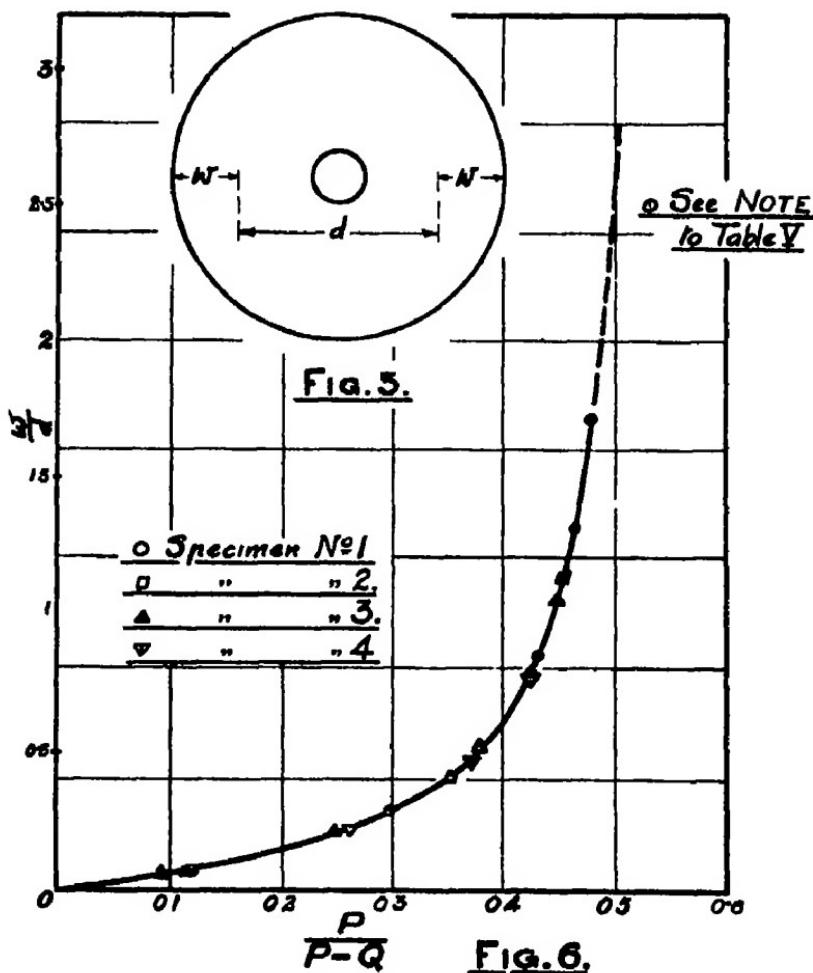


TABLE V.

Specimen 1		Specimen 2		Specimen 3		Specimen 5	
w/d	p/p + q	w/d	p/p + q	w/d	p/p + q	w/d	p/p + q
1.71	0.477	1.13	0.453	1.045	0.448	0.771	0.424
1.31	0.464	0.77	0.424	0.793	0.424	0.470	0.371
0.85	0.430	0.416	0.352	0.526	0.380	0.226	0.260
0.29	0.296	0.072	0.115	0.219	0.246	0.740	0.120
2.50	0.530	—	—	0.000	0.093	—	—

Note. The last item for specimen 1 is founded on the approximate law $p + q = -26.86/r^2 + 0.07/r^4$ which is applicable to the higher stress-differences. This point has been included in Fig. 6 to show that the rate of increase of the stress difference falls off as the inner radius of the cylinder is approached.

On reference to either Table II. or Fig. 2 it will be seen that the measurements have not been taken as far as the inner radius, as the discovered law, quoted above breaks down in this region. The want of uniformity thus revealed may be explained by assuming that the material is stressed beyond the so-called elastic limit, and this contention is supported by the few measurements that have so far been possible, which indicate that the rate of increase of the stress-difference is not so rapid as the discovered law would indicate if extrapolated into this region.

Conclusions

There can be no doubt that the distribution of stress across the walls of long or short thick cylinders is given by the equations derived from the theorem of Lamé, so long as the material at the radius considered is not strained beyond the range of linear proportionality. Such strain measurements that were made (see Table II.) confirm this, but it should be pointed out that the increase in the external diameter is dependent upon the over-stressed material as well as upon that not over-stressed. The data at present available, however, suggests that the law, in this region, is of the form:—

$$p + q = a - b/r^2 + c/r^4 - \text{etc.}$$

where a , b and c are constants.

In view of the experience so far gained from this preliminary work, similar series of tests are being prepared which have for their object the measurement of the resulting strain across the walls of open ended metal cylinders made of different materials.

The author takes this opportunity of thanking Engineer-Commander C J Hawkes, R N (ret), Professor of Engineering at Armstrong College, Newcastle-upon-Tyne, in the University of Durham, for his cordial support of this work, to Messrs C V Miller, B Sc A S Knolles, B Sc, and P Nath, B Sc, for their valuable assistance in taking some of the readings, and to the Standing Committee for Research of Armstrong College for additional apparatus.

THE VOLCANIC HISTORY OF SOUTHERN FIFE.

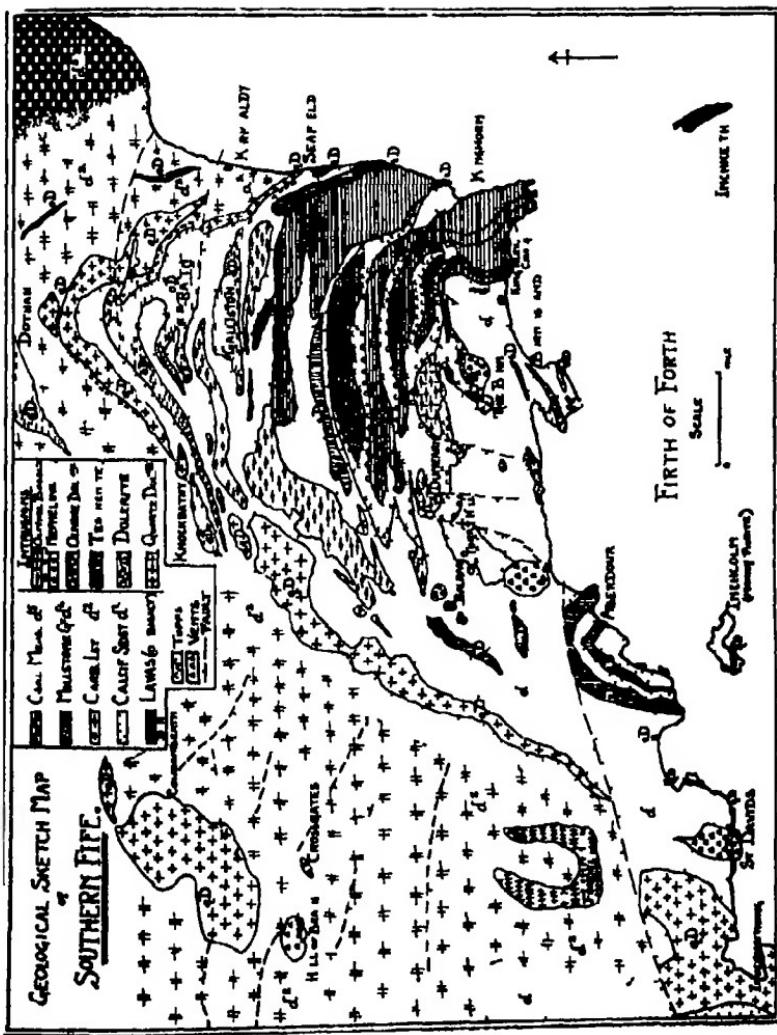
By DOUGLAS A. ALLAN, B.Sc., Ph.D., F.R.S.G.S.

The Midland Valley of Scotland has proved, by reason of its wealth of exposures of igneous rocks, a fruitful field for the study of certain phases of vulcanicity of the past. A general account of the igneous geology of the area was given by the late Sir Archibald Geikie in his "Ancient Volcanoes of Great Britain" (1897), and subsequent investigations have yielded an ever-increasing mass of valuable data regarding the volcanic activity which manifested itself during the Lower Old Red Sandstone and Carboniferous periods. In the region under consideration, Southern Fifeshire, there is a group of volcanic necks, lava flows, dykes, and sills associated with sediments of Carboniferous age, which presents numerous interesting features. The petrography of some of these exposures has been dealt with by the author in an earlier publication* and the present contribution, while summarising that work and bringing it up to date, is concerned also with certain wider aspects of the problems of the district.

The rocks of Southern Fife form an anticline, the pitch of which is a little to the east of north. In the core of the fold is revealed the major part of the Calciferous Sandstone Series and enveloping it is the Carboniferous Limestone Series. (See fig. 1.) The overlying Millstone Grit, Coal Measures, and Upper Red Coal Measures are disposed in synclines to the east and to the north of the anticline. Throughout the area is a number of faults, some of considerable magnitude, with a general radiate disposition from the core of the anticline.

At many places the sedimentary rocks have been truncated by volcanic vents which are in the main perpendicular to the plane of the bedding of the country rock. In

* *Trans. Roy. Soc. Edin.*, Vol. LIII., 1924, p. 479.



100

size there is much variation; the Hill of Beath vent has a larger diameter of nearly 3,000 feet—that at King Alexander's Craig measures barely 150 feet across. The principal content of the volcanic necks is a greenish or greyish ash. Within the vents themselves or in their vicinity there are in many cases intrusions of fine-grained olivine basalt. Among the sediments they appear as sills but where ash is the surrounding medium they occur as dykes. (See fig. 2.)

In the district immediately to the north and east of Burntisland is exposed a series of lava flows, fifteen hundred feet in thickness, interbedded with normal sediments. (See fig. 1.) The rocks are in general rather fine-grained olivine basalts of the Dalmeny, Hillhouse, and Kinghorn types.* It has been found possible to group the lava flows together in accordance with this classification, and to establish a series of zones. The island of Inchkeith is composed of a continuation of the lavas of Kinghorn. At the west end of Inchcolm,† and at Aberdour on the same strike,‡ are lava flows of Dalmeny type basalts. Their horizon is not known accurately, but it is thought to be well below that of the Burntisland group.

The intrusions of the area form a not inconsiderable chapter in the history of its vulcanicity. While there are numerous dykes and sills in close association with the vents, this phase of igneous activity is to be found in its greatest development in the region surrounding that which contains the majority of the necks and the lava flows. There sheet after sheet has been intruded, their superficial area as at present exposed far exceeding that of the lava flows (See fig. 1.)

The products of intrusion show variety both in composition and texture, and may be considered most simply, perhaps, according to the following grouping:—

(a) Olivine-bearing rocks are represented by basaltic varieties (Dalmeny, Hillhouse, and Dunsapie

* *Trans. Roy. Soc. Edin.*, Vol. LIII., 1924, p. 484.

† *Trans. Geol. Soc. Edin.*, Vol. IX., 1908, p. 121.

‡ *Trans. Roy. Soc. Edin.*, Vol. LIII., 1923, p. 386.

types), and by doleritic varieties either porphyritic and sub-ophitic (Gulliston type) or non-porphyritic and strongly ophitic.

- (b) Analcite-bearing rocks, always containing olivine or its replacement products, are found in the basaltic and doleritic types of teschenite occurring within the district. Biotite is an almost constant accessory and in some cases hornblende is present in addition.
- (c) A nepheline-bearing basalt has been discovered recently near Inverkeithing by the writer and a detailed description of it is in course of preparation. This is the first definite occurrence of nepheline in Southern Fife, and it serves as an important link with the felspathoid-carrying rocks of Eastern Fife.* In his paper on "The Lower Carboniferous Volcanic Rocks of East Lothian (Garleton Hills),"† F. H. Hatch mentions that a rock similar to that from Inverkeithing occurs at Hill of Beath, in Southern Fife, but in the material collected from that place during the course of this investigation, no nepheline has been identified so far.
- (d) At Burntisland Docks there are two prominent outcrops of a rock unlike those previously described. The examination of the nature of this rock was rendered difficult by the fact that practically all of the material collected was highly decomposed, the only fresh minerals being felspar, a very pale brownish augite, and occasionally some very small fragments of quartz, set in a turbid matrix which was taken to be the remains of an intersertal mesostasis. It was therefore retained in the olivine-free group of Drs. Hatch and Watts as described in the Memoir of the Geological Survey on Central and West

* Mrs Wallace, *Trans. Geol. Soc. Edin.*, Vol. X., 1916, p. 248.

† *Trans. Roy. Soc. Edin.*, Vol. XXXVII, 1892, p. 116.

Fife (1900),* and at the same time its close relationship to the quartz dolerites was affirmed. The recent investigation of the dolerite of Dalmahoy in Midlothian by Dr. R. Campbell and Mr. J. W. Lunn has resulted in the Burnt-island rock being grouped with it. Chlorophæite which they have discovered in the Dalmahoy specimens has now been identified in the fresher material a closer search has yielded from the Burntisland intrusion.†

- (e) The rock type which contributes to a most striking extent to the intrusions of Southern Fife is quartz dolerite. It is essentially a quartz, plagioclase, augite rock, the fresher specimens of which usually contain a fair amount of hypersthene. Allport as early as 1874‡ described the occurrence of chlorophæite in the quartz dolerite of South Queensferry.

From the brief description just given of the products of the vulcanicity of Southern Fife it is not difficult to perceive the essential homogeneity of the assemblage. The olivine dolerites and the olivine basalts differ only in their texture. The discovery that analcite occurs as an almost constant accessory mineral in these rocks indicates their kinship with the teschenites. With the exception of the sparing occurrence of biotite in the Dunsapie type olivine basalt, black mica and hornblende are apparently confined in their distribution to rocks containing analcite or nepheline in fair amount. The nepheline basalt at Inverkeithing contains both biotite and analcite in fair quantity and so links together the normal basalts on the one hand and the teschenites on the other. Detailed chemical analyses of the various rock types yield indisputable proof of their monogenetic character. (See table at end.) Finally the gap between the olivine-bearing suite and the

* Loc. cit., p. 81

† *The Mineralogical Magazine*, Vol. XX., No. 110, 1925, p. 440.

‡ *Quart. Journ. Geol. Soc. Lond.*, 1874, Vol. 30, p. 557.

quartz dolerites is bridged by the rocks of Burntisland Harbour. It may be mentioned of the olivine-bearing rocks that in some cases they possess a picrite facies at the base.

The compact assemblage of volcanic vents, lava flows, and intrusions, coupled with the strong evidence of the monomagmatic origin of the materials, make it possible to attempt a reconstruction of the sequence of events in the igneous activity of the region. Of the fifteen necks mapped, eight cut stratigraphical horizons higher than the earliest lava flows, and therefore cannot have served as the orifices from which these flows were emitted. Of the remaining seven vents, four are associated with deposits of tuff of considerable lateral extent, most suggestive of the wide spread of pyroclastic material usually found in the vicinity of the more important volcanic cones, and it is significant to note that this ash occurs about the horizon of the first lava flows. In answer to the contention that these vents may be merely the stumps of volcanic pipes which passed up through younger strata since removed by denudation, it may be stated that an examination of the fragments of sedimentary rocks from the agglomerates yielded no material of an age demonstrably more recent than that of the surrounding strata. The Binn at Burntisland, which incorporates two of the necks, is thought by reason of its large size and central position to be most probably the focus of dispersion of most of the surface products of vulcanicity in the area (see Fig. 1). Below this main ash horizon, the bore at Whinnyhall has revealed the presence of several thin beds of ash which together with the Aberdour lava flows heralded the greater activity to come.

The vents at Kirkcaldy, Hill of Beath, and Crossgates penetrate the lower members of the Carboniferous Limestone Series and are therefore younger than the lavas of the Burntisland district, which are confined to the Calciferous Sandstone Series, if the Seafield Tower Limestone is taken to be the equivalent of the Hurlet Limestone. The older survey maps show two lava flows in the

Carboniferous Limestone Series one a little north of Kirkcaldy railway station and the other at Dothan (see Fig. 1). The former rock in ophitic olivine dolerite is well exposed in the railway cutting where contact alteration and a transgressive junction indicate its intrusive nature. The Dothan rock is in living dolerite closely akin to some of the material of the Ruth Hill sills near Kirkcaldy and is converted partially to a White Trap in places. This is in itself most suggestive of an intrusion but even stronger evidence is obtainable from mine workings in the vicinity where the coal is reported to be reduced locally to a cinder mass.

The dykes, bosses and sills of olivine basalt were developed in all probability soon after the effusion of the lavas if they were not in part contemporaneous with them, so similar must have been the conditions of consolidation as shown by their texture and structures. It is noteworthy that the majority of the intrusions of Hillhouse type basalts occur not far from the horizon of the lavas of the same type while the stratigraphically higher group of sills of Dalmeny type basalts show a similar relationship to the later lava flows of the same composition—an arrangement in keeping with the suggested near contemporaneity of the intrusions with the effusive basalts. If this hypothesis be admitted, the olivine dolerites must of necessity represent a later phase of the igneous activity as they are present in force at the top of the Calciferous Sandstone Series (see Fig. 3) and in the overlying Carboniferous Limestone Series. In two places in Southern Fife is there evidence that the quartz dolerites are of later formation than the olivine dolerites. On the island of Inchcolm an E.W. quartz dolerite dyke cuts across a picrite teschenite sill,* and at Knockbathy a quartz dolerite sill otherwise continuous for fully twelve miles, has forked against an olivine dolerite sill, expanding somewhat in area and becoming much finer in texture.

* R. Campbell and A. G. Stenhouse *Trans. Geol. Soc. Edin.* Vol IX 1908 p 180

On the question of the conditions maintaining in the area during this period, a considerable amount of evidence is available fortunately, all of which points to the sub-aqueous extrusion of the lava flows, although the presence of fragments of fossil wood in the agglomerate at the necks suggests that the craters reared their heads above water and were clothed with vegetation. Associated with the lavas are well-bedded sandstones containing the tests of marine organisms together with a varying proportion of tuffaceous material. In the interval between successive flows, beds of shale were deposited, and in one case the oncoming mass of molten rock tore up portions of the sediment and carried them a short distance. Beds of limestone of restricted extent have been found occupying hollows on the surface of the underlying basalt, and occasionally such calcareous accumulations yield valuable material to the paleobotanist. That the concentration of calcium carbonate in the water was sufficient to permit precipitation, is also indicated by the strong development of calcite in threads and veins and along the joint planes in the igneous rocks.

It is a common observation that the volcanic rocks of the Lower Old Red Sandstone period are highly decomposed in comparison with the remarkably fresh condition of the Carboniferous igneous material. The proportional difference in age seems an insufficient reason for so marked a variation in the degrees of freshness. It must be admitted, however, that the Lower Old Red Sandstone rocks in many cases passed through a cycle of denudation in Upper Old Red Sandstone times additional to those shared with the Carboniferous strata. It would be of considerable importance if we could ascertain how much of the weathering of the Lower Old Red Sandstone lavas took place immediately after each eruption. If, as is generally supposed, they flowed over a land surface or into lake basins subjected to periodic desiccation, we have a clue to their acute decomposition. The Lower Carboniferous lavas flowed into water and were quickly covered

up, for accumulation of sediment is rapid round the margins of a basin of deposition such as Southern Fife must have been as is indicated by the fact that the Calciferous Sandstone Group at Bishop Hill is less than 170 feet thick while at Burntisland twelve miles to the south it includes fully 600 feet of normal sediments. Further south in Midlothian, the same group is over 5 000 feet thick. The sequence of the sedimentary rocks interbedded with the lava flows of Southern Fife, while indicating variation in the depth of the sea shows that the general trend was towards progressive submergence of that area culminating in the deposition of the marine limestones of the Carboniferous Limestone Series.

The volcanic history of Southern Fife is intimately connected with that of West Lothian in point of view both of time of occurrence and of the products of the igneous activity. The earlier vulcanicity of Arthur Seat in Midlothian,* soon after the commencement of the Carboniferous Period gave rise to a suite of olivine bearing rocks not so very different from those described in the present paper. Regarding the age of the vents in Eastern Fife there is still some controversy, but the one at Lundin Links is certainly Post Coal Measures, and is of special interest in that the agglomerate was found to contain a weathered fragment of quartz dolerite, while that at Largo Law has been demonstrated only recently to be of Carboniferous Limestone age †. There is thus strong evidence, in the areas mentioned for the continuity of volcanic activity from the commencement of Carboniferous times on to the Permian.

The writer is indebted to Dr Frederick Walker of the University of St Andrews for permission to publish his recent analysis of a Dalmeny type olivine basalt given on the appended table. Acknowledgment is also due to Dr Hickling for helpful criticism.

* Mem Geol Survey The Geology of the Neighbourhood of Edinburgh 1910 Chap VII

† D Balsillie Geol Mag Vol LX 1923 p 580

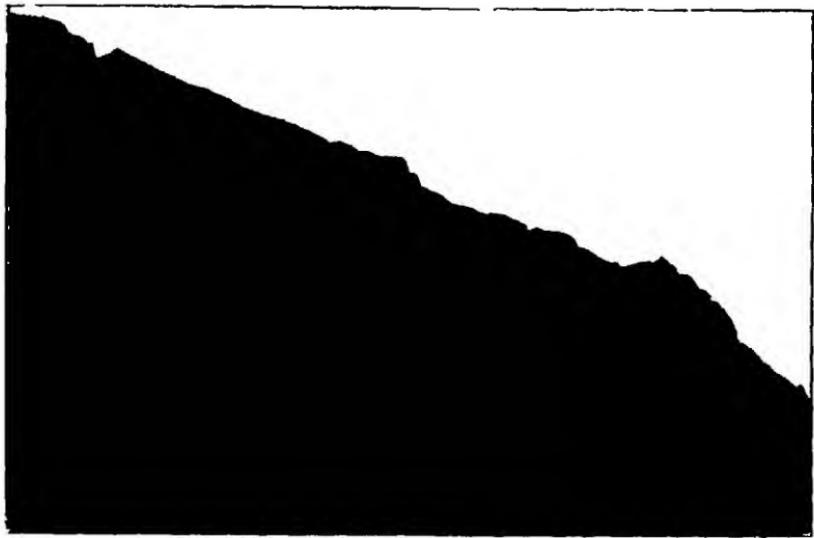


FIG. 2

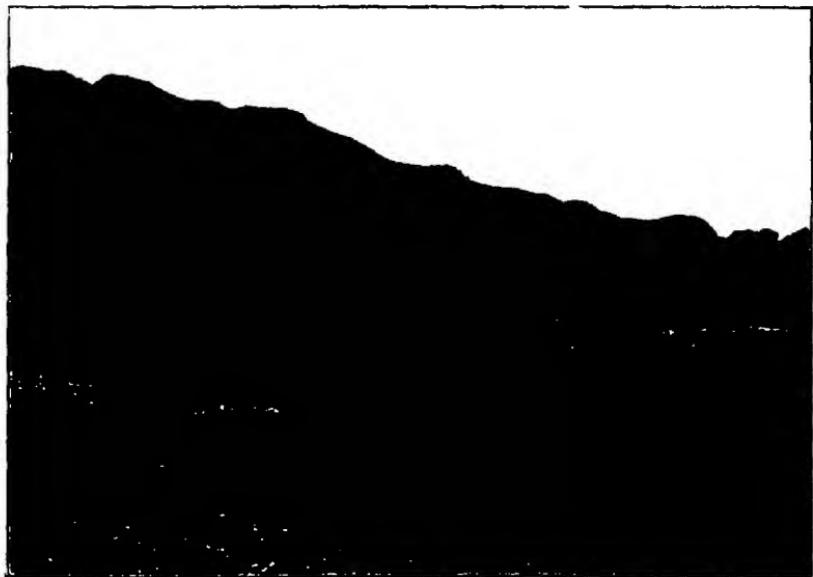


FIG. 3

CHEMICAL ANALYSES

	I	II	III	IV	V
SiO ₂	44.18	44.50	43.56	42.49	44.62
Al ₂ O ₃	13.56	14.48	13.77	13.87	10.80
Fe ₂ O ₃	1.21	3.13	2.50	2.59	5.00
FeO	8.83	9.01	9.51	9.32	8.26
MgO	10.47	12.28	10.81	11.21	10.51
(CaO)	9.93	9.55	10.00	9.76	6.29
Na ₂ O	2.45	1.77	2.72	2.39	1.50
K ₂ O	0.97	0.79	0.46	0.87	0.23
H ₂ O at 105° C	0.44	0.60	0.77	0.47	—
H ₂ O above 10° C	2.40	1.80	2.45	3.35	5.50
TiO ₂	2.44	1.90	2.85	2.51	1.64
P ₂ O ₅	0.60	0.18	0.27	0.61	0.29
MnO	0.18	0.20	0.24	0.29	0.20
Cr ₂ O ₃	n.d.	n.d.	n.d.	n.d.	0.07
(CoNi) ₂ O	n.d.	nil	nil	0.09	0.02
IrO	n.d.	n.d.	n.d.	n.d.	0.03
BaO	n.d.	n.d.	n.d.	0.04	0.13
CO ₂	nil	nil	nil	0.22	0.04
	99.64	100.17	99.91	100.06	100.13

n.d.—Not determined

I—Dalmeny Type Basalt High Binn Burntisland

Analyst F Walker Communicated privately Sp Gr = 2.96

II—Galliston Type Dolerite Galliston Quarry Kirkcaldy

Analyst W H Herdsman Sp Gr = 2.98

Trans Roy Soc Edin vol lxxi 1924 p 497

III—Kinghorn Type Basalt Chuck Hall Quarry north of Burntisland

Analyst W H Herdsman Sp Gr = 2.97

Trans Roy Soc Edin vol lxxi 1924 p 497

IV—Hillhouse Type Basalt Hillhouse Quarry Linlithgow

Analyst F G Radley *Mem Geol Surv Scot The Geology of the Glasgow District 1911 p 134*

V—Piorite Colinswell Burntisland

Analysts Harrison and Reid H S Washington *Chemical Analyses of Igneous Rocks 1917*

Analysis IV is of a rock which is in every way similar to those of the same type in Southern Fife and is included for comparison

EXPLANATION OF ILLUSTRATIONS

MAP (page 91)

- 1 Sketch map of Southern Fife, showing the general disposition of the igneous rocks. In the key to the shading for Olivine Basalts D signifies Dalmeny type and H signifies Hillhouse type

PLATE (Figs. 2 and 3)

- 2 —The Binn, Burntisland A dyke with columnar jointing cutting across the agglomerate, in which numerous bombs can be seen. The weathering of the ash is characteristic.
- 3 —Toschenite sill south of Seafield, Kirkcaldy The intrusion has forked, and transgressive junctions can be seen both above and below the sediments

KAOLINITE BEARING NODULES FROM NORTHUMBERLAND COAL MEASURES

By S. TOMKIEFF

Separtian clay ironstone nodules with cracks filled up with kaolinite and calcite were found in a shale underlying the High Main coal seam at Cowgate Newcastle-on-Tyne. The powdery white mineral from the cracks was subjected to a microscopical and chemical analysis and proved to be in almost pure kaolinite corresponding to the theoretical formula $2\text{H}_2\text{O Al}_2\text{O}_3 2\text{SiO}_4$. Some of the hemispherical kaolinic aggregates which were lining the walls of the cracks had a radiating fibrous structure each fibre consisting of a single kaolinite crystal.

The nodules were composed of two distinct parts (1) An external laminated shell enclosing (2) a compact septarian core. Those two parts of the nodule were analysed both chemically and microscopically (micro sections and leevigated residue). The shale in which the nodules were imbedded was subjected to the same analysis. Each chemical analysis was recalculated into a norm mineralogical composition and by means of a partial analysis of the insoluble residue of the nodule the percentage of the shale material in the nodule was calculated. This gave the opportunity of calculating the relative amount of the compression of the shale (1/7) checked by a direct measurement of the thicknesses of the lamellas in the shale and in the nodule.

The probable mode of origin of the kaolinite bearing nodules together with the shale in which they are imbedded is as follows -

- (1) Deposition of laminated mud in an estuary or lagune rich in vegetation

- (2) Concentration of colloidal iron carbonate in the form of nodules under the influence of humic bodies and the activity of plants.
- (3) Consolidation of colloform nodules into crystalloidal masses with a subsequent setting and cracking of the interior.
- (4) Gradual compression of the laminated mud into a shale under the influence of accumulating sediments.
- (5) Infilling of the septarian cracks with kaolinite and calcite which were precipitated from an aqueous solution and probably derived from the surrounding shale.

THE STRUCTURE OF ARAGONITE.*

By S. TONKIN.

An attempt has been made to construct a leptonic model of aragonite (orthorhombic variety of calcium carbonate) by combining the X-ray method with a new method of etch-figures.

A leptonic model of aragonite constructed in such a way that its transformation into calcite can be attained with a small expenditure of energy, was tested by means of the method of etch-figures, and a perfect agreement was reached between the figures observed and those deduced. The spacings of the leptonic model are in perfect agreement with those observed by W. L. Bragg, with the exception of two faces the spacings of which are half of the observed. There are certain indications that aragonite as a metastable phase of calcium carbonate tends to pass into calcite even at normal temperature, and that aragonite in its natural state may be partially transformed into calcite. This could explain the abnormal spacings in the X-ray spectra.

The constructed leptonic model of aragonite belongs to the space group C_{2h}^1 and, therefore, aragonite is not orthorhombic as previously thought, but monoclinic. This fact, already remarked upon by some mineralogists, definitely places aragonite in the holohedral class of monoclinic system. But as its crystallographic axes are orthorhombic, morphologically aragonite must be considered as a pseudo-orthorhombic crystal.

* A complete account is published in the *Mineralogical Magazine*, Vol. XX., No. 110, p. 408, September, 1925.

University of Durban Philosophical Society, 1923-25.

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100 0 0					Balance forward
					100 0 0
Balance forward					

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	£2 10 0	£2 10 0
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Balance Sheet

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Reserve Fund	100 0 0	100—5% War Loan at cost
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4th November, 1923

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1924

- Nov 13th — The Structure of Aragonite with special reference to the new Etched Figures Method of Crystal analysis By S Tomkeieff
- 24th Further properties of Celluloid illustrating Basic Principles of the Optical Method of Measurement of Stress and Strain By H F I Martin B Sc
- Dec 8th — Carbonates of Glycol and Glycerol By W Maw
An Investigation of Aromatic Arsenicals by the Method of Thermal Analysis By S Peat
The effect of Electrical Discharge on Mercury Vapour By G E Stephenson

1925

- Jan 21st The Founding of Modern Science By Prof Irvine Masson
- Feb 5th The Photo activation of Chlorine By W Taylor B Sc
The Force between two Magnetic Spheres By A Elliott B Sc G W Brydon B Sc and R G Iunnon M A M Sc
- 6th — The Inheritance of Prejudice By Prof A Meek D Sc
- 17th On a Parasite presumably producing False Finger and Toe of Sweden By A W Bartlett M A M Sc
A contribution to the Knowledge of the Biochemistry of Respiration of the Plant Cell By M Thomas B A
- 27th — Lebesgue Integration By D C Colborne M A
- Mar 9th — A redetermination of the Atomic Weight of Boron affording evidence of variation in the Isotope ratio for samples of diverse origin By Prof H V A Briscoe D Sc and P L Robinson M Sc
- 12th The Head Structures of a Permian Shark By Prof Hickling D Sc
- , The Volcanic History of Southern Fife By D A Allen Ph D
- May 19th — Kaolinite bearing Nodules from the Newcastle Coal Measures By S Tomkeieff

Vol. VII., Part 3

PROCEEDINGS

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THE CRYSTALLISATION OF METALS.

By PROF CECIL H DODSON, F R S,
Department of Metallurgy University of Sheffield

The fact that all metals are crystalline is of the greatest importance for the consideration of their properties, for the manufacturer as well as for the scientific investigator. Most metals and alloys are melted and allowed to solidify at some stage in the process of manufacture, and the arrangement of the crystals determines to a large extent the possibility of further treatment, such as forging or rolling. The growth of crystals differs somewhat from that of salts, with which we are most familiar in the laboratory. A salt growing from solution under normal conditions has a fairly simple form, such as that of a cube, octahedron, or prism. Only under exceptional conditions is complex branching observed. On the other hand, metals usually grow by preference in the form of highly branched crystals, known as dendrites, and the interlocking of these dendrites builds up the mass of an ingot. In the first stage of solidification, the branched crystals grow perpendicularly to the cooling surface of the mould, their longest axes being directed towards the interior, but at a later stage fresh nuclei make their appearance spontaneously in the midst of the fluid mass, and new dendrites grow from them, the direction of the axes being determined by chance, so that no such regularity is found as in the outer layer of crystals. When the whole mass has become solid, the dendrites have grown so as to be in complete contact with one another. They thus divide the ingot or casting into a large number of irregular polyhedra, but as these are in perfect contact

no structure can be seen on cutting through the mass. On etching such a cut section with an acid or other reagent which attacks the metal, however, the structure is revealed. The reason is that the neighbouring polyhedra, although chemically the same, differ in their orientation, that is, in the direction of their crystal axes relatively to the plane of the section. A crystal is not attacked by a solvent equally in all directions, but penetration occurs more readily along certain planes. Neighbouring polyhedra, or crystal grains as they are usually called, are thus attacked to an unequal extent, whilst the contact of two grains sets up a difference of potential, so that the boundaries are often more attacked than the mass. An examination under a high magnification shows that each etched grain has become covered with minute facets, and the varying direction of these facets, causing greater reflection in certain directions, gives rise to the characteristic appearance of an etched metallic surface.

The boundaries between the grains are determined by the meeting of neighbouring dendrites, but there is some interest in examining the form of those boundaries. In a few instances it is possible to separate the grains of an ingot. Certain brasses, for example, break up into their constituent grains when immersed in mercury, amalgamation occurring very readily along the boundaries. Such grains are found to be polyhedra with curved faces, often pentagonal. It was suggested by Quincke that just before solidification a liquid metal separated into two immiscible liquid phases, which together formed a foam, solidification then taking place within the foam cells. If this were so, the shape of the grains should be the same as that of the cells in an extended mass of soap foam. A statistical examination of a large number of foams and of several metals shows that such a resemblance does in fact exist. When the frequency of occurrence of 3-, 4-, 5-, 6-, and 7-sided faces is plotted, the two graphs fit one another almost perfectly. The maximum is at 5, that is, pentagonal faces are the most common, the grains varying

about the pentagonal dodecahedron as a mean. This form, even with curved faces, does not fill space, so that odd corners have to be filled by small tetrahedra and hexahedra. The theoretical form of the perfect foam cell, Kelvin's tetrakaidecahedron, a 14-faced figure with 8 hexagonal and 6 square faces, the edges of which are curved, is not observed, either in ordinary foams or in metals, although Dewar has obtained it in single chains of cells in soap foams.

It does not follow from these observations that Quincke's supposition is correct, and there are other strong reasons for believing that the separation into two liquid phases is unlikely. It may, however, be concluded that the form of the boundaries is determined by surface tension, but the surface tension is probably that between the growing crystal and the liquid, and not between two liquids. Little is yet known of the surface tension of solids but a few experiments are easily made. When a button of gold is melted and allowed to solidify without disturbance, it may often form a single crystal, but the surface is completely rounded. Microscopical examination shows that it is wrinkled by the stresses set up during contraction, the appearance being exactly that of an amorphous mass, such as gelatin. On etching with aqua regia, the outer skin is removed, and small octahedral facets appear. These may take the form of sharp pyramids. On heating to a temperature of 600-700° C., far below the melting point of the metal, the sharp angles of the pyramids become rounded, and they ultimately flow down, giving once more the smooth, glossy surface which was there before etching. Surface tension has thus determined the appearance rather than crystalline cohesion. It may be supposed that the cohesion and the surface tension both diminish as the temperature rises, but at unequal rates, so that at some temperature, still far below the melting point, the surface tension predominates. The experiment may be confirmed by examining the behaviour of minute crystals of gold, prepared by chemical means. Under similar conditions,

they become rounded and ultimately form spheres at temperatures below the melting point. As a guess, it may be supposed that those metals which have the greatest surface tension in the liquid state will also have the greatest in the solid state and it is in fact found that metals of high surface tension, such as gold and copper are more apt to form rounded dendrites when crystallising from alloys than metals of low surface tension such as antimony. On these lines an investigation of the process of crystallisation in metals is being conducted.

THE CRYSTAL STRUCTURE OF SOME OXALATES

By J. F. WOOD M.Sc. A INST P. EARL GREY MEMORIAL FELLOW



Monoclinic Prismatic

Specific Gravity = 1.64

$$\beta = 106^\circ 12'$$

$$a : b = 1.6949 \quad 1 : 3.3360$$

Cleavage {110} imperfect

Assuming for the moment that there are two molecules in the unit cell the dimensions of the cell can be calculated and are found to be—

$$\begin{aligned} a &= 6.10 & | \\ b &= 3.61 & | \\ c &= 12.05 & | \\ \beta &= 106^\circ 12' \end{aligned}$$

The spacing of any set of crystal planes can now be calculated and compared with the value determined by X-ray measurement

The following measurements were taken —

Plane	1st order reflection	Observed spacing	Plane	1st order reflection	Observed spacing
101	big	4.76 Å	full	111	big
001		5.81	full	212	full
100		2.92	full	121	not found
103		2.86	full	311	very small
102	small	1.81	full	112	big
104	very small	1.17	full	010	very small
101	big	5.97	full	011	big
201	very small	1.31	full	021	very small
203	not found			110	3.45
102	big	2.41	full	012	big
					3.08

In the fourth and eighth columns the remark "full" means that the calculated and observed values of the crystal spacing agree. The remark " $\frac{1}{2}$ " means that the observed value of the crystal spacing is one half that of the calculated value.

From these results it is seen that the crystal spacings calculated on the assumption that there are two molecules of oxalic acid in the unit cell agree with the values obtained by experiment, with certain exceptions. These exceptions are the (010) plane and planes whose indices are of the form (hkl) where $(h+l)$ is odd. From consideration of these abnormal cases the relative positions of the molecules in the cell and the symmetry of the molecule can be deduced.

If we place molecules, similarly oriented, at the corners of the cell, then since each corner is common to eight similar cells, the total contribution to the cell by the molecules at each corner is one molecule. The second molecule remains to be placed. It is seen that the (100), (010), (001) planes have each a value which is half that calculated from the dimensions of the cell given above. Each of these planes, then, must be interleaved half way by a second set of planes, and it can easily be realised that this can only be brought about if the second molecule occupies the centre of the cell. The molecules at corners and those at centres of cells cannot be identical because in that case the crystal aggregate would be built up on the body centred lattice and any plane (hkl) such that $h+k+l$ is even would give an experimental value for the crystal spacing one half that of the calculated value. This is not found to be the case in oxalic acid. The two molecules in the cell then must be different, their difference being, of course, simply one of orientation. For convenience we may call the molecules occupying the corners A molecules and those the centres of cells B molecules.

The relative positions of the A and B molecules have been determined and it now remains to determine the symmetry of the molecule itself and the relative orientations of the A's and B's.

That the molecule itself must possess some type of symmetry is obvious from the following argument. Monoclinic prismatic crystals, to which class oxalic acid belongs, are distinguished by the possession of two symmetry elements: (1) a plane of symmetry, reflexion across which brings the crystal to self coincidence; (2) and perpendicular to this plane a digonal axis of symmetry, rotation of π about which brings the crystal to self coincidence. Since the unit cell is such that, on indefinite repetition in space, it gives the actual crystal, then it follows that whatever symmetry elements are possessed by the actual crystal must also be possessed by the unit cell. Now if a crystal, which possesses a plane of symmetry, only is built up of asymmetrical units (molecules) then two types of such units must be present, each being the reflection of the other across the symmetry plane. Similarly in the case of a crystal possessing a single digonal axis, and built up of asymmetrical units, there must be present two types of molecule one of which is the rotation of the other through π about that axis. In the class of crystals under discussion four types of asymmetrical unit are required and this group of four placed at each point of one or other of the monoclinic lattices gives the actual crystal structure. In such a case there would be four molecules in the unit cell and since oxalic acid has only two molecules it follows that the oxalic acid molecule possesses some symmetry of its own which must be one of the symmetry elements of the monoclinic prismatic class: (1) a plane of symmetry; (2) an digonal axis of symmetry, or (3) a centre of symmetry. (A body has a centre of symmetry when reflexion across a plane, followed by a rotation through π about an axis perpendicular to the plane brings the body to self coincidence.)

If we suppose the molecule of oxalic acid possesses a centre of symmetry, and the molecule of type B is obtained from type A by reflection across the symmetry plane a model shows that the abnormal values of the spacings of the (010) and (*hol*) planes when $(h+1)$ is odd are to be expected. The alternatives (1) and (2) lead to different

conclusions. To sum up then oxalic acid is built up from a unit cell of the following dimensions:—

$$\begin{aligned} a &= 6.10 \\ b &= 3.61 \\ c &= 12.05 \end{aligned} \quad \left. \begin{array}{l} \\ \\ \end{array} \right\} \text{Å.}$$

$$\beta = \hat{a}c = 106^\circ 12'$$

and contains two molecules, one at the corners and one at

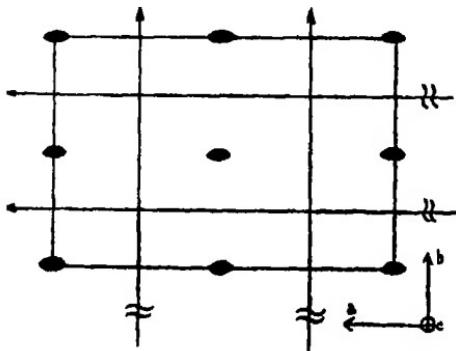


Fig I
Space Group of Anom Oxalate Q_3
● 2-axis \parallel to c -axis
 \leftrightarrow 2-axis (screw) \parallel to $a+b$
axes \perp of pitch $\frac{3}{2}$ + $\frac{5}{2}$ respectively

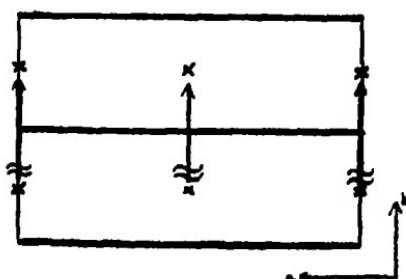


Fig II
Space Group of Methyl Oxalate C_{2h}
— Line of Reflection

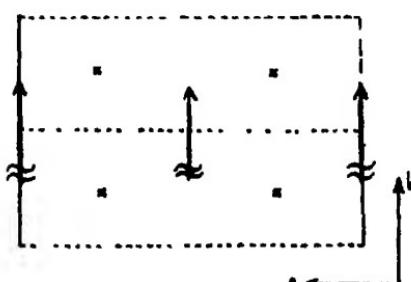


Fig III
Space Group of Oxalic Acid C_{2h}
... ... Glide plane of Reflection
x Centre of Symmetry

the centre of each cell. The molecule has a centre of symmetry. The space group to which the crystal is referred is $\text{C}_{\bar{1}}$ Fig. 3 (see Hilton *Mathematical Crystallography*, also Astbury and Yudley *Phil. Trans. Series A*, Vol 224 pages 221-257 1924)

Ammonium Oxalate $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$

Rhombic bisphenoidal

$$a = b = 7799 \quad c = 3700$$

Specific gravity = 1.46 to 1.50

Again assuming that there are two molecules in the unit cell the dimensions of the cell are found to be —

$$\begin{array}{l} a = 8.06 \\ b = 10.34 \\ c = 3.82 \end{array} \quad \left. \right\} \text{Å}$$

The following crystal planes were examined —

Plane	Calculated spacing	Observed spacing	Orders of reflection					
			1	2	3	4	5	6
110	6.4	A	6.44	A	10	200 (app) —	—	—
110	6.4		6.44		60			
100	8.06		4.03		0	13	0	40
010	10.34		> 11		45	0	40	0
120	4.39		4.29		25			
001	3.82		3.72		60	20	—	—
111	3.25		3.23		40	0	—	—
331	1.85							
113	1.25							
531	1.85							
		not found						

It is seen from the above table that all the observed crystal spacings agree with the values calculated on the assumption that there are two molecules in the unit cell with the exception of the (100) and (010) planes. These planes have a spacing of half the calculated value. This result indicates that ammonium oxalate is an example of the space group $\text{Q}_{\bar{1}}$ (see Fig. 1). The molecule of ammonium oxalate has a diagonal axis coinciding with the crystallographic C axis. The molecules are arranged in the cell one at each corner and one at the centre of the (001) faces.

Methyl Oxalate. $(\text{CH}_3)_2 \text{C}_2\text{O}_4$.

Monoclinic Prismatic.

$$a : b : c = 3.320 : 1 : 5.226.$$

$$\beta = 103^\circ 22'$$

Specific gravity = 1.46. Cleavage (010) perfect.

The dimensions of the unit cell are calculated to be:—

$$\begin{array}{l} a = 3.93 \\ b = 11.84 \\ c = 6.17 \end{array} \quad \left. \right\} \text{ Å}$$

$$\beta = 103^\circ 22'.$$

If we suppose that there are two molecules in the cell, X-ray analysis shows that the calculated and observed values of the crystal spacings are in agreement with the single exception of the (010) plane which has a spacing half the calculated value. This indicates (see Astbury and Yardley, *Phil. Trans.* quoted above), that methyl oxalate is an example of the space group C_{2h}^1 (see Fig. 2).

Since there are only two molecules in the unit cell, the molecule must have some symmetry of its own, and reference to Fig. 2 shows that this must be either (1) a plane or (2) a centre of symmetry. The second molecule is half-way along the b edges of the cell.

In the above work a Bragg ionisation spectrometer was used and the X radiation, that of the rhodium $K\alpha_2$ line ($\lambda = .616 \text{ Å}$). The work was carried out partly at University College, London, and at the Royal Institution. In conclusion the author wishes to express his indebtedness to the Research Committee of Armstrong College for financial assistance and to Sir William Bragg for his never failing interest and kindly encouragement.

THE EXAMINATION OF X-RAYS BY THE METHOD OF CLOUD-PHOTOGRAPHY.

By ORRELL DARBYSHIRE, M.Sc.

Cloud-photographs of tracks of ionising particles ejected by X-rays first obtained by C. T. R. Wilson¹ provided very convincing evidence as to the real nature of the process of ionisation of gases by X-rays. They afforded direct and absolute proof of the suggestion previously made by W. H. Bragg that the whole of the ionisation by X-rays may be regarded as being due to β -rays arising from the X-rays, the X-rays being effective in liberating corpuscles each with energy sufficient to enable it to produce a large number of ions along its course. The results of subsequent investigations on X-rays by the cloud-method form the subject of a paper published in 1923.² The use of a stereoscopic camera in this latter work made it possible to visualise the tracks three-dimensionally and examine them with respect to origin, initial direction, range, form and ionisation. Such examination elicited a number of features consonant with modern concepts of atomic structure and with the quantum theory of radiation. In the further development of the subject attention has been paid almost entirely to the examination of initial direction of ejection of the β -particles. Wilson had already intimated the existence of two types of asymmetry of initial direction. One is characterised by an excess of tracks having their initial portions in or near the plane containing the X-ray pencil and its electric vector (lateral asymmetry), the other by an excess of tracks having a forward component in their initial velocities (longitudinal asymmetry). The former reveals the partial polarisation of the primary beam, the

¹ Proc. Roy. Soc. A., Vol. 85 (1911), Vol. 87 (1912).

² Proc. Roy. Soc. A., Vol. 104 (1923).

preponderance of primary X-rays whose electric vector is in the plane containing the cathode-stream. The latter has been accounted for qualitatively on the basis of Richardson's hypothesis that the absorption of a quantum $h\nu$ of energy is accompanied by the transference of the momentum of the absorbed radiation causing a resultant motion in the forward direction.¹ Making additional rather arbitrary assumptions F. W. Bubb² and P. Auger³ have derived certain quantitative relations which may be expected to hold

In experimental work F. W. Bubb,⁴ O. K. de Foe,⁵ D. H. Loughridge⁶ and F. Knichner have, like Wilson, adopted stereoscopic photography. In longitudinal asymmetry investigations the "mean-axis" of the stereo-camera lenses was directed at right-angles to the X-ray pencil and in lateral asymmetry investigations parallel to it.

The author has drawn attention to the difficulty of ascertaining initial directions of tracks correctly by the above stereoscopic procedure.⁷ It appeared that by replacing stereo-photography by photography in two directions at right-angles much greater precision in the determination of forms and initial directions of tracks would be attained. Further, such photography would eliminate two other difficulties inherent to stereoscopic examination of lateral asymmetry in which the photographs are taken end-on to the beam. Tracks would be formed across the complete width of the chamber (20 cms. say) and it is impossible for all to be sharply focussed. Also, even in the absence of this difficulty overlapping and confusion are inevitable. In "right-angle" photography two separate cameras could be disposed so that their lens-axes and the X-ray pencil were mutually perpendicular. The photographs so obtained would be free from both the above defects whilst lateral asymmetry

¹ "Electron Theory of Matter," p. 488

² *Phil. Mag.*, 49, May, 1925 ³ *Comptes Rendus*, June 8, 1925

⁴ *Phys. Rev.*, 23 Feb., 1924. ⁵ *Phil. Mag.*, 49, May, 1925

⁶ *Phys. Rev.*, Dec., 1925. ⁷ *Nature*, Sept. 11, 1926.

would still be amenable to examination and that with increased precision.

THEORY.

With origin O (Fig. 1) take rectangular axes of co-ordinates, Ox along the X-ray pencil, Oy parallel to the horizontal camera axis and on the same side of Ox as the camera, Oz parallel to the vertical camera axis.

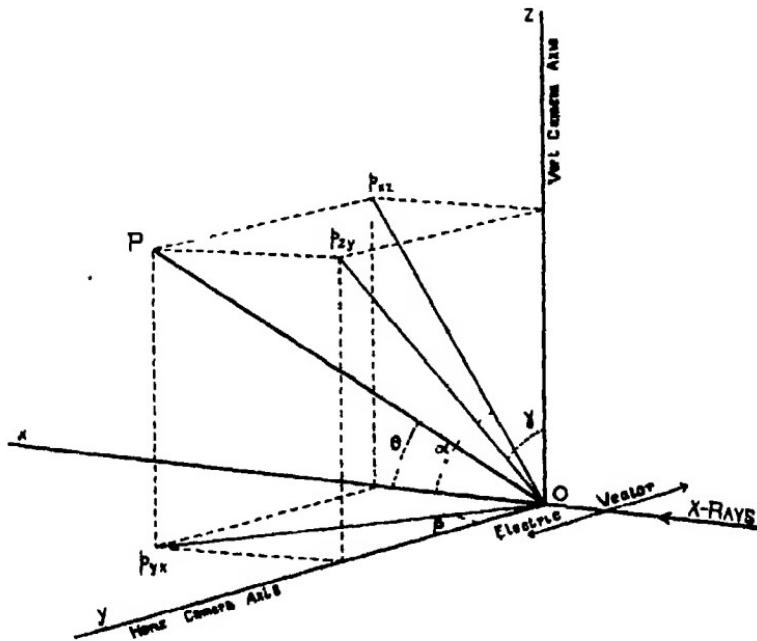


FIG. 1.

The disposition of the X-ray tube was such that the electric vector was parallel to Oy .

Let OP be initial direction of track and O_{p_x} , O_{p_y} , O_{p_z} the projections as shown. Call angles XO_{p_x} , YO_{p_y} , ZO_{p_z} , POX , α , β , γ , θ , respectively.

The projections O_{p_x} , O_{p_y} are photographed by the vertical and horizontal camera respectively. The angles α and β are measured by means of a low-power microscope having vertical motions and vernier scales.

The angle γ , whose statistical value gives a measure of lateral asymmetry is then given by $\gamma = \tan^{-1} (\cot \alpha \cdot \cot \beta)$.

θ , giving a measure of longitudinal asymmetry is given by

$$\theta = \cot^{-1} \left[\frac{\tan \beta}{\sqrt{1 + \tan^2 \alpha \tan^2 \beta}} \right].$$

It is possible to obtain the three co-ordinates of any point on a track and, therefore, the true path of the β -particle in its flight through space can be determined.

EXPERIMENTAL PROCEDURE.

In essentials the apparatus and method are as used by Wilson.¹ The expansion apparatus is of the Wilson type though rather larger than that described by him, the diameter of the expansion-chamber being 20 cms. The cylindrical wall is of thin glass producing negligible distortion of the track-photographs. In it are three holes, two at opposite ends of a diameter and the other mid-way between. One, through which the X-ray pencil is admitted diametrically after passage through a lead collimator, is closed by celluloid. Through the opposite one a pin may be admitted for focussing and reference purposes. Through the third hole gases other than air may be admitted. The Wimshurst machine has sixteen 3-foot diameter plates and is driven by a motor. The Leyden jar battery for the production of the illuminating spark has a capacity of about 06 microfarad. The mercury-lamp consists of a tube of "Durosil" glass bent twice at right-angles and is of elliptical cross-section the major axis and length being parallel to a cylindrical lens and at a distance from it equal to its focal length, viz., 3 cms. The matched lenses of the cameras are Beck Isostigmat, Series II., No. 3, of focal length $4\frac{1}{2}$ inches, angle 70° and intensity-ratio variable from $f/5.8$ to $f/32$. The cameras are rigidly supported, their axes being vertical and horizontal respectively and both at right-angles to the X-ray pencil. They are fixed at such a distance from the X-ray pencil as to give

¹ Loc. cit.

photographs of unit magnification. The photograph (Fig. 2) shows the cloud chamber cameras and mercury-lamp in position. The X-ray tube inside a lead screened box is so placed that the cathode stream is horizontal.

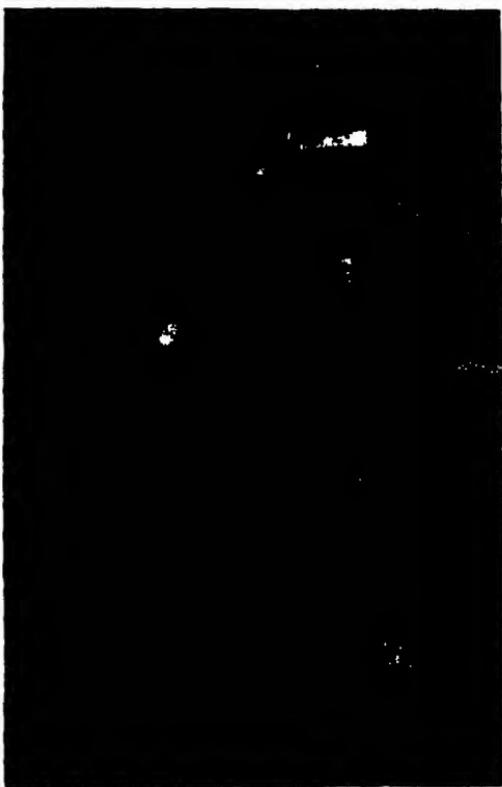


FIG. 2

It was found (as had been anticipated) that whilst ample light was scattered forwards giving good records in the horizontal camera so little was scattered at right angles, that is vertically that the tracks were not recorded on the negative in the vertical camera. This difficulty was overcome by causing the light incident on the tracks to pass in a direction bisecting the angle between the lens-

axes. For this purpose a total reflecting prism 7.5 cms. long, 3.5 cms. hypotenuse, mounted in a metal tray was fixed to the piston floor of the chamber in the appropriate position with respect to the mercury-lamp and the X-ray pencil (Fig. 3). Crevices were closed with wax and gelatine to obviate convection currents. Condensation on the prism was reduced by coating it with transparent gelatine.

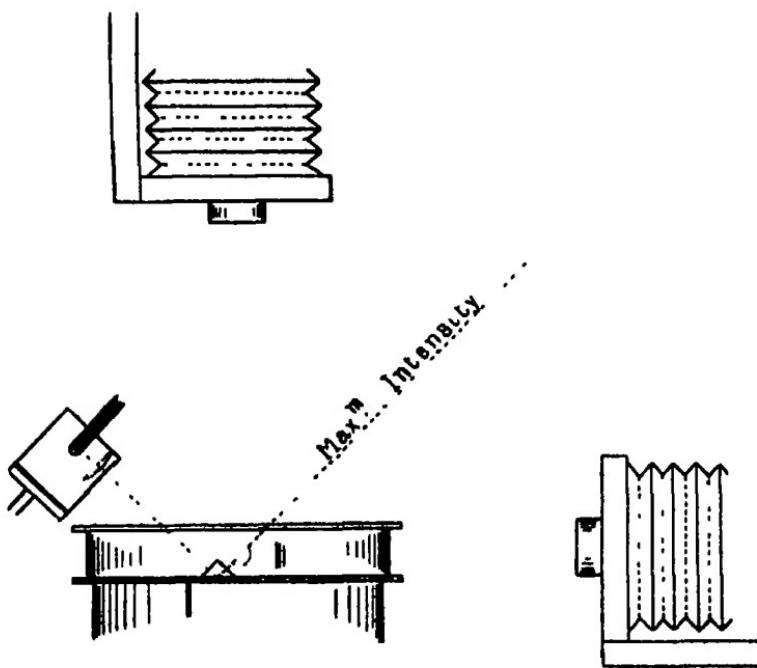


FIG. 3.

Photographs so obtained were of satisfactory and approximately equal density.

The three "events" of the method, expansion, X-ray flash, illuminating spark, were caused to occur in rapid succession with the correct time intervals by a falling ball and spark-gap arrangement (Fig. 2). To obtain tracks of satisfactory sharpness over their whole lengths the necessary precautions were taken.

RESULTS.

As a preliminary test of the method the angles α and β have been measured in the cases of twenty-eight tracks occurring in four pairs of photographs and the corresponding values of γ and θ deduced.

The complements of γ (the angles between the plane containing the X-ray pencil and electric vector and the plane containing the pencil and the initial directions of ejection of β -particles) are as follows:

2, 3, 3, 4, 6, 8, 8, 9, 10, 16, 18, 21, 22, 23, 29, 33, 34, 37, 39, 41, 48, 52, 62, 66, 70, 77, 90, 90 degrees. 55 per cent. of these values are between 0° and 30° , 26.7 per cent. between 30° and 60° and 17.8 per cent. between 60° and 90° . A marked tendency for β -particles to be ejected in or near the plane containing the cathode stream is thus indicated (lateral asymmetry) and accords with the classical theory of the partial polarisation of X-rays.

Nineteen β -particles have initial forward motion as against nine having initial backward motion (longitudinal asymmetry).

The values of θ are as follows:

19, 23, 27, 47, 48, 48, 49, 51, 51, 53, 53, 63, 64, 65, 67, 74, 76, 77, 84, 92, 97, 113, 116, 127, 134, 137, 139, 145 degrees. Sixteen of the twenty-eight β -particles were thus ejected within the angle θ 45° to 90° . Apparently under the conditions of these experiments in which the X-rays were heterogeneous and the gas in the chamber moist air, a most probable value of θ exists between 45° and 90° . It is to be expected that, using homogeneous X-rays and single gases the most probable values of θ , θ_m say, would depend on the wave-length of the radiation and on the nature of the gases. From statistical observations on a sufficiently large number of tracks produced by homogeneous X-rays in moist, but otherwise single, gases the effect on θ_m of varying X-ray wave-length and the gas independently should be possible and of considerable interest.

These two co-existent asymmetrical phenomena gain

interest from the fact that whereas one is best explained on the classical theory of radiation the other seems to be a definite quantum effect. If we abandon classical considerations and attempt to explain lateral asymmetry on the basis of the quantum theory we must regard the quantum "bundle of energy" as having definite asymmetrical directional properties for it appears to impart its $h\nu$ energy to an orbital electron in a direction always at right-angles to its direction of motion and in a definite plane, namely, that containing the cathode-stream. Both asymmetries are "diluted" as a result of the momenta of the electrons in their atomic orbits.

In conclusion, I wish to record my indebtedness to Mr. A. F. Blaylock, M.Sc., for his very valuable help in the practical procedure involved in these experiments and to Professors Stroud and Todd for their interest and encouragement in the work. A portion of the apparatus has been purchased by means of a grant made by the Royal Society.

NOTE ON THE BENDING OF STRUTS OF VARYING CROSS-SECTION.

By J. A. WILCOX, B.Sc., Ph.D.

Euler's Theory of a strut or column acted on by a force in axial direction has been the subject of much controversy since it first appeared in the Mémoirs of the Berlin Academy of 1759, and various alternatives have been offered, of an empirical or speculative order. It would appear, however, that within the range of approximation implied in the assumptions, and these are clearly defined and of the order usual in engineering, the formula leaves little room for improvement, and no further justification is offered for making it the basis of the present investigation.

A more or less complete bibliography of the subject will be found in Todhunter and Pearson's *History of the Theory of Elasticity*, and, for newer work, more modern Treatises on Strength of Materials, such as *Cook*, (Arnold, London, 1925).

We consider a strut of length l , simply supported at both ends and axially loaded with a force P . Assuming the deflections y to be small, so small that the curvature of the neutral axis may be written $\frac{d^2y}{dx^2}$, and neglecting the shortening of the strut by bending and compression, we establish the equation of bending moment at any point, x from one end, in the form

$$EI \frac{d^2y}{dx^2} + Py = 0, \quad \dots \quad \dots \quad \dots \quad (1)$$

subject to the boundary conditions as inferred from the mode of support,

$$y^0 = y^l = 0 \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

I being the moment of inertia of the cross section at x , and E the modulus.

When I is variable, the solution to the fundamental equation (1) can be obtained in finite form in two cases, namely when

$$\frac{P}{EI} = (\alpha + \beta x)^{-4} \quad (3)$$

and when

$$\frac{P}{EI} = (\alpha + \beta x)^{-3} \quad (4)$$

The first form is seen to cover the case of a strut of square or circular cross-section with a linear variation of side or radius ("straight taper"), but it is easily extended to more general forms, such as cross-sections consisting of two or four members (plates or angle-iron) symmetrically placed with respect to a principal axis, by writing the moment of inertia

$$I = I_0 + \xi^2 S.$$

Where I_0 is the moment of inertia of the individual members with respect to an axis through their centroid, S the total area and ξ the distance from the centroids to the principal axis. The last term usually predominates in lattice-braced columns.

The second form corresponds to a linear variation of area, or a bulging (parabolic) outline.

1. Straight Taper Columns.

Writing the fundamental equation

$$\frac{d^2y}{dx^2} + k^2 y = 0 \quad (5)$$

we are led to try a solution in the form

$$y = \phi e^{i\psi} \quad (6)$$

where ϕ and ψ are real differentiable functions of x , which on substituting in (5) and separating real and imaginary quantities are found subject to the conditions

$$\frac{1}{\phi} \frac{d^2\phi}{dx^2} + \left\{ k^2 - \left(\frac{d\psi}{dx} \right)^2 \right\} = 0, \quad (7)$$

$$\phi^2 \frac{d\psi}{dx} = \text{const.} \quad (8)$$

The first of these equations is obviously satisfied by taking

$$\psi = \int k dx$$

provided that

$$\frac{d^2\phi}{dx^2} = 0,$$

and this conforms with

$$\phi = (\alpha + \beta x)$$

$$k = \text{const } (\alpha + \beta x)^{-1}$$

leading to

$$\psi = (\alpha\beta + \beta^2 x)^{-1}$$

Our solution may then be written

$$y = (\alpha + \beta x) A e^{i(\alpha\beta + \beta^2 x)^{-1}} + B e^{-i(\alpha\beta + \beta^2 x)^{-1}}$$

or, in trigonometric form,

$$y = C(\alpha + \beta x) \sin \{(\alpha\beta + \beta^2 x)^{-1} - \theta\} \quad (9)$$

The first of the boundary conditions (2) now gives

$$\theta = l/\alpha\beta$$

and, including the minus sign in the constant C, we may therefore write

$$y = C(\alpha + \beta x) \sin \{x/\alpha(\alpha + \beta x)\} \quad (10)$$

The second boundary condition requires

$$C(\alpha + \beta l) \sin \{l/\alpha(\alpha + \beta l)\} = 0 \quad (11)$$

and, excluding the trivial case $C = 0$, corresponding to an unbent column (in unstable equilibrium for sufficiently large loads), and also the case $\alpha + \beta l = 0$ which has no practical application, making the value of y/l indeterminate, we can satisfy the equation (11) only by such values as render

$$l/\alpha(\alpha + \beta l) = m\pi$$

m being any integer. With the usual definition of the crippling load P_1 , corresponding to $m = 1$, and substituting the values as obtained from (3),

$$\alpha = \sqrt{EI/P}$$

$$\alpha + \beta l = \sqrt{EI_1/P}$$

where I_0, I_1 denote the extreme moments of inertia, we have

$$P_i = (\pi^2 E/l^2) \sqrt{I_0 I_1} \quad (12)$$

Hence, the crippling load of a straight tapered column is determined by the geometric mean of the two extreme moments of inertia

The deflection at any point can be written

$$y = \text{const.} \times \sqrt[4]{I} \sin(x\sqrt{P/E \sqrt{I_0 I_1}}) \quad (13)$$

and the maximum deflection determined by differentiation, from equation (10), leading to a transcendental equation

$$\tan\{\alpha/a(a + \beta x)\} = -\{\beta(a + \beta x)\}^{-1} \quad (14)$$

of the type first discussed by Fourier, and solved by successive approximations

2. Parabolic Columns.

When the fundamental equation is of the type

$$\frac{d^2y}{dx^2} + (a + \beta x)^{-4} y = 0 \quad (15)$$

we attempt a solution in the form

$$y = (a + \beta x)^m$$

and find on substituting in (15), as a conditional equation for m ,

$$\beta^2 m(m-1) + 1 = 0$$

$$m = 1/2 \pm \sqrt{\frac{1}{\beta^2} - \frac{1}{4}}$$

$$= 1/2 \pm i\mu$$

denoting $\mu = \sqrt{\beta^{-2} - \frac{1}{4}}$ (16)

The solution may thus be written

$$y = (a + \beta x)^{\frac{1}{2} \pm i\mu} \{A(a + \beta x)^{i\mu} + B(a + \beta x)^{-i\mu}\} \quad (17)$$

Consider first the case $\beta^2 < 4$, that is μ real, and write the equation (17) in trigonometric form, making the substitution,

$$(a + \beta x)^{\pm i\mu} = e^{\pm i\mu \log(a + \beta x)} \quad (18)$$

thus obtaining

$$y = C(a + \beta x)^{\frac{1}{2}} \sin\{\mu \log(a + \beta x) - \theta\} \quad (19)$$

The first of our boundary conditions (2) determines

$$\theta = \mu \log a$$

and so the deflection becomes

$$y = C(a + \beta x)^{\mu} \sin \{\mu \log (1 + \beta x/a)\} \quad (20)$$

The second boundary condition is as usual satisfied by $C = 0$ and by $a + \beta l = 0$ but excluding these two cases which are of no interest we must have

$$\mu \log (1 + \beta l/a) = m\pi \quad (21)$$

m being any integer The crippling load P is therefore determined by

$$\mu \log (1 + \beta l/a) = \pi$$

and from (4) we now obtain writing as above I_0 and I_1 for the extreme values

$$\left. \begin{aligned} a &= \sqrt{EI/P} \\ a + \beta l &= \sqrt{EI/P} \\ 1 + \beta l/a &= \sqrt{I/I} \\ \beta &= \frac{1}{l} \sqrt{E/P} (\sqrt{I} - \sqrt{I_0}) \end{aligned} \right\} \quad (22)$$

and thus

$$\left. \begin{aligned} \mu &= \sqrt{\beta^{-1}} \\ &= \sqrt{(Pl^2/E)} / (\sqrt{I} - \sqrt{I_0}) \end{aligned} \right\} \quad (23)$$

Substituting these values above we find for the crippling load after reduction

$$P = (E/l^2)(\sqrt{I} - \sqrt{I_0})^2 \{(\pi / \log \sqrt{I/I_0})^2 + \frac{1}{4}\} \quad (24)$$

The deflection at any point can then be written

$$y = C \sqrt{I} \sin (\mu \log \sqrt{I/I_0}) \quad (25)$$

It remains to examine the case of $\beta^2 > 4$ The solution to the fundamental equation (15) is then in exponential form with real indices or involving hyperbolic functions and therefore has only one zero point for finite values of the arbitrary constant It is therefore not possible to fit both boundary conditions except for a column remaining straight

and thus bending is in this case impossible. The condition is expressed in terms of the constants of the column, and the load as follows,

$$(E/Pl^2)(\sqrt{I_1} - \sqrt{I_0})^2 > 4$$

or after reduction,

$$P \leq (EI_0/4l^2)(\sqrt{I_1/I_0} - 1)^2 . \quad (26)$$

This equation, therefore, provides a least value of the load, below which the column can not be adequately treated on the lines of Euler's Theory.

Comparing our results as given in equations (12) and (24) with the value of the crippling load that obtains for a uniform cross-section, $I_1 = I_0$, it is seen at once, that when the taper of the straight tapered column becomes vanishingly small, as when I_1 approaches I_0 , the formula (12) becomes identical with Euler's classical value.

In the case of a parabolic column, when I_1 becomes equal to I_0 we must have $\beta = 0$ since otherwise the cross-section would vanish at the middle. If we now write

$$\sqrt{I_1} = \sqrt{I_0}(1 + \gamma)$$

γ being a small, ultimately vanishing quantity, and substitute in (24), we find

$$P_1 = (E/l^2)\{\pi^2 I_0 \gamma^2 / \log^2(1 + \gamma) + \gamma^2 I_0 / 4\} \quad (27)$$

And so, since in the limit

$$\gamma / \log(1 + \gamma) \rightarrow 1,$$

$$\text{line } P_1 = \pi^2 EI_0 / l^2.$$

SOME FURTHER POINTS IN CONNECTION WITH THE THEORY OF ROWING.

By F. H. ALEXANDER, M.Sc., M.Inst.N.A.

A former paper entitled "The Theory of Rowing" gave the results of investigations into the speeds of movement of boat, crew, and oars, during the performance of a stroke, in the case of a racing eight. The present paper gives the results of investigations mainly intended to determine the ratio of useful to total expenditure of energy by the oarsman.

It is, however, desirable, in the first place, to correct an error which appeared in the earlier paper. The pressures upon the oar blade were computed by using the speed (V_t) normal to blade axis, and shown in Fig. 6 of that paper. None of the critics of the paper seemed to have noticed the error of method, but its recognition has led to correction of the earlier calculations in several particulars.

Fig. 1, given here, is intended to replace the original Fig. 6, and shows an additional line (V_a) as well as a rearrangement of the others. (V_a) represents, in direction and magnitude, the speed of approach between the water and the element of blade under consideration. The pressures upon the blade should be computed upon the speed (V_a), and the angle (α) which it makes with the blade surface.

Amendment of the calculations upon this basis, shows that the time taken in performing the stroke should be much less than that stated in the earlier paper. Fig. 2 is now given to illustrate the speeds concerned in a stroke which is believed to be more in accordance with actual practice.

There are five periods concerned in the complete movement of the oar. (ab) lasting 0.019 sec. is spent in air

while accelerating and dropping. (*bc*) lasting 0.020 sec. is used for entry. During (*cd*) lasting 0.482 sec., the oar blade is fully covered and doing its full work. Extraction is performed during 0.014 sec. (*de*), and (*ef*) lasting 0.015 sec. is spent in air while the oar is brought to rest.

The oar is performing propulsive work from (*b*) to (*e*) during 0.516 sec.; and this may be defined as the "stroke"

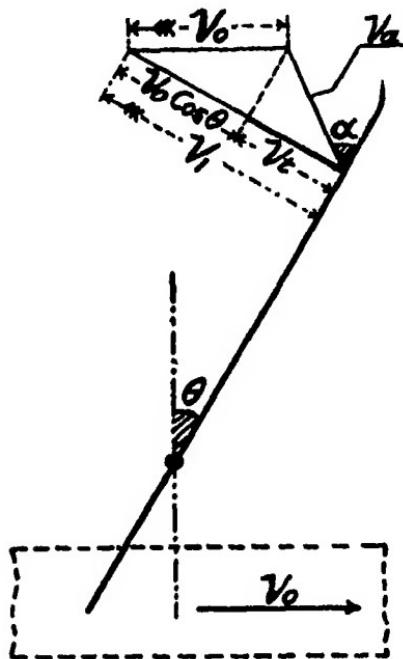


FIG. 1.

proper, as the times spent in air are usually included in "run."

The total angular sweep of the oar, in relation to the thole pin, is 80° , of which 50° is swept through from rest to the thwartship position (*g*), and this takes about two-thirds of the time. An examination of cinematograph films confirms this time ratio. The angular movements in air are very small, being 0.56° at beginning and 0.67° at finish. It is possible that a slightly earlier entry of the

blade tip (causing a small back splash), would be an advantage. I am informed that some coaches aim at obtaining the splash as an indication of a "quick beginning."

The rate of striking is 36 to the minute thus allowing 1.716 secs for stroke and run together. If time in air is all included in run, the ratio of run to stroke becomes 2.32

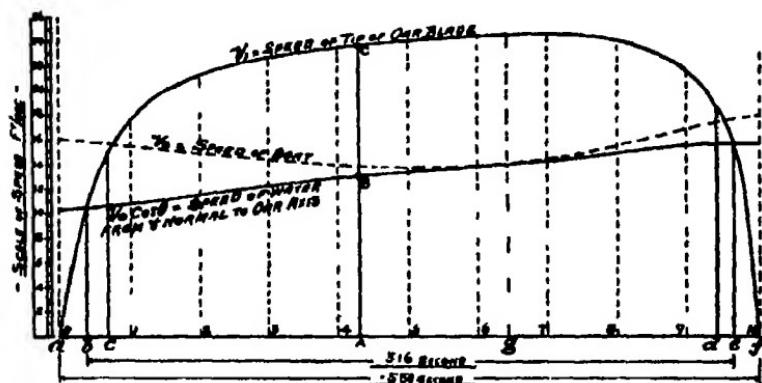


FIG. 2.

which is much more in accordance with the usual rhythm than the value obtained in the earlier paper.

Since that paper was read before this Society, the Oxford University Press has published Dr. Bourne's "Textbook of Oarsmanship," in which there is much suggestive reference to theory, as well as the most complete exposition of the anatomical side of the oarsman's art that has ever been published. Dr Bourne lays great emphasis on the importance of "stroke diagrams" in the study of oar movements, and I fully agree with him. Some of his stroke diagrams were obtained after careful study of the movements of a model oar operated in fine sand, so that its paths might be traced and observed at leisure in a manner impossible in the case of water. His insistence upon the fair or smooth character of the curve of turning points is useful in the detection of the faults revealed by a diagram.

Fig. 3 shows the "stroke diagram" associated with the speeds given in Fig. 2; and Fig. 4 shows the curve of turning points. Consideration of the relationship between Fig. 2 and Fig. 4 has led to an interesting and useful discovery.

If, in Fig. 2, an instant of time (A) is chosen then (AC) represents the speed of tip of blade normal to axis, and if the length of our oarboard is (l) feet, any intermediate speed such as (AB) is that of a point on the oar axis at a

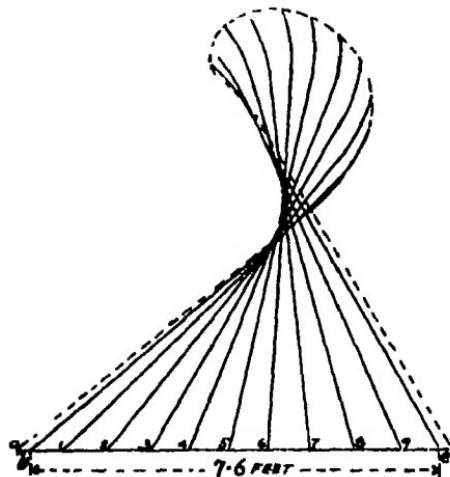


FIG. 3.

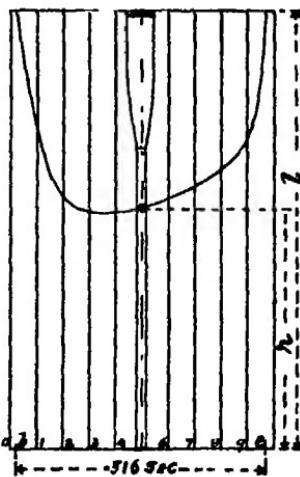


FIG. 4.

distance $(\frac{AB}{AC} \times l)$ feet from the hole pin. Now at (B) the speed of the oar towards the water is the same as that of the water away from the oar, so that they are relatively at rest; there is no slip.

Turning then to Fig. 4, make $r = (\frac{AB}{AC} \times l)$ and the point so given establishes the turning point at the instant considered. The curve of turning points so obtained constitutes an accurate check upon the correctness of Fig. 3; but the most useful feature of the relationship is to be found in that it enables a diagram of speeds of movement, such as Fig. 2, to be derived from a photographed stroke

diagram, such as Fig. 3. It is hoped to get some films of strokes viewed from above during the coming rowing season.

Before leaving Fig. 3, it may be pointed out that the direction indicated by (V_a) in Fig. 1 is tangent to the locus of movement of the element concerned; so that, for instance, the dotted line showing the movement of our tip in Fig. 3 would have as tangent at any given instant, the (V_a) appropriate to the tip at that instant; and (V_a) would be constructed from the values of (V_i) and (V_o) , derived from the corresponding Fig. 2.

It may be of interest to record that the resistance of the boat, used in the 1921 calculations, was estimated to be 84 lbs. including wind resistance upon the crew, and 77 lbs. excluding that resistance, when the speed was 17 ft. sec. No experimental data had been published, at that time, with regard to the resistance of such long narrow boats, and thus the whole of the calculations and results, then given, depended upon the reasonable accuracy of an estimate made upon very slender information. In 1922, however, Sir John E. Thorncroft had some towing experiments made upon models of racing eights for Dr. Bourne, and the deduced resistances for the corresponding full-sized boats are given on page 221 of Dr. Bourne's book. It is there seen that the resistances of three different types of boat vary from 72 lbs. to 77 lbs. at a speed of 17 ft. sec. It may be claimed, therefore, that the basis of the former numerical work was substantially in accordance with actual conditions in fine weather.

In stating the mechanical efficiency of rowing it is necessary to be clear as to what the ratio relates to. We may consider: (a) the effective propulsive work; (b) the work done during stroke only at the oar handle; (c) the total work done by the oarsman upon his own body as well as upon the oar, during both stroke and run. It is evident that the ratio $(\frac{a}{c})$ is less than the ratio $(\frac{a}{b})$. Again, if we take into account the speeds of expenditure of energy, we may state efficiencies in terms of power rather than of work.

For the purpose of this paper, it is proposed to state the efficiencies in terms of work, and to illustrate their determination by a numerical example, relating to the case already used.

Assume a mean sustained speed of 17 ft. sec., and that conditions of wind and water cause the mean resistance against the boat to be 90 lbs. The distance covered in one minute is 1,020 feet and therefore the effective propulsive work done against resistance is 91,800 ft. lbs. Each member of the crew has, as his share, 11,475 ft. lbs., and, at 36 strokes per minute, the effective work done is 328 ft. lbs. per stroke per man.

The distance moved by the boat while the blades are in the water is 760 feet, therefore the mean effective pressure on each blade is $\frac{328}{760} = 43.2$ lbs. in a fore-and-aft direction

As the blade moves outward and inward during stroke as well as fore-and-aft, the 43.2 lbs. is a component of the larger pressure normal to the oar axis. This mean normal pressure is 49.5 lbs. The leverage ratio of the oar is 2.4, so that the mean force exerted on the oar handle, normal to axis, is $2.4 \times 49.5 = 118.8$ lbs. It may be stated that the maximum force is 159 lbs. The distance moved by the centre of effort of the hands is 4.46 feet, and therefore the work performed upon the oar is 4.46×118.8 lbs. = 530 ft. lbs. Thus we may state the efficiency of the stroke itself to be the ratio $(\frac{a}{b}) = \frac{328}{530} = 0.62$. It is interesting to find that this ratio closely corresponds with that given by mechanical means of propulsion such as paddles and screws.

Now it is not possible to estimate the relative efficiencies of varying styles of rowing, and rates of striking, unless one takes into account the large amount of what may be termed "unproductive" work employed during both stroke and run. This work is due to the forces necessary for accelerating and retarding the bodies of the crew and their oars, and for meeting resistances to their movements. For equal distances moved, the velocities vary as the rate

of striking, and the accelerations and accompanying forces vary as the square of the rate of striking. Powers expended vary as the cube of the rate of striking.

In the example we are considering, it has been calculated that the unproductive work, done during stroke and run combined, is just 530 ft. lbs., of which almost five-sixths is concerned with stroke. Thus, at 35 strokes per minute, the unproductive work is equal to the productive work, and the efficiency ratio may, from this point of view, be stated as $\left(\frac{n}{c}\right) = \frac{328}{1060} = .31$. It is debatable how far this efficiency ratio may be fairly used for comparison with mechanical propulsion, but it is of interest to express the efforts of the crew in terms of horse-power.

It is evident that the rate of expenditure of energy is much higher during stroke than during run owing to the more rapid movements, and it is found that, including the unproductive work, each man develops no less than $3\frac{1}{2}$ horse-power for the short period of about half-a-second while making the stroke. During the longer period of run, the horse-power is only about $\frac{1}{7}$. For a complete minute of rowing the average horse-power is nearly $1\frac{1}{2}$, and the crew therefore develop 10 horse-power.

The 91,800 ft. lbs., already referred to as work due to resistance, represents 278 horse-power, and this means that a motor of about $4\frac{1}{2}$ horse-power should be sufficient to maintain the boat at a speed of 17 ft. sec. or nearly 10 knots.

With regard to the horse-power developed by oarsmen, some interesting experiments were conducted by Dr. Kendall Henderson at Yale University, and, as these were carried out from an entirely different point of view, I may make a few brief quotations from an account of them which came into my hands.

"The Yale men, when racing, breathed from 60 to 70 litres of air a minute" "it follows that the Yale men—and, no doubt, the members of the Oxford and

Cambridge eights—are capable of averaging $1\frac{1}{2}$ horse-power each during a four-mile race." This would mean 12 horse-power for the crew, and appears to indicate that there are certain sources of expenditure of energy, some of them probably physiological, which are not taken account of in my analysis of the mechanical problem. And, to this it must be added, that the stroke to which my numerical values relate is not put forward as an example of the best or strongest rowing. Longer and more powerful strokes are rowed by many oarsmen, and, during parts of a race, a higher rate of striking is associated with these strokes, so that the development of $1\frac{1}{2}$ horse-power by an oarsman seems reasonable. It is probable that the work done at the oar handle, during stroke, frequently exceeds 600 ft. lbs. in the case of a first-class man.

It was pointed out, in the earlier paper, that, the drop in speed of boat during stroke, is actually an assistance to the oarsman, in that it allows him to get the necessary thrust with less speed of oar, and prolongs the time during which he gives the boat acceleration. It has been suggested that the drop in speed can be completely counteracted by the acceleration, if the oar blades are got to work soon enough. This is, however, fallacious, because only part of the pressure on the stretcher is balanced by pressure on the thole pin; there still remains the sternward pressure needed for accelerating the oarsman himself.

It has frequently been urged that the wide angles, used in England at commencement and finish of stroke, are detrimental to efficiency, as the thwartship components of force are then so great. Now it is not possible to get rid of the periods of acceleration and retardation, and the wider apart these periods are, the greater is the angular sweep of the oar when full work is being done, and the blade being pulled through as fast as it will go. There is inevitably a loss of some effective work, and of the resulting acceleration given by the stroke. The rate of striking must therefore be increased, and this leads to such an increase of expended energy, as is likely to counterbalance any possible gain. It appears as if the amplitude of stroke

should be determined, for each oarsman, by his anatomical ability to perform it with sufficient ease and rapidity

Returning to the subject of unproductive work, it is possible to explain thereby the reasons why bucketting and the rowing of rapid strokes involve a higher expenditure of energy than the long stroke and low rate of striking, usually advocated in this country. If two boats are proceeding at the same speed, but one crew is striking at 36 and the other crew at 40 to the minute the latter may save in productive energy per stroke, but will not save any in the minute. Of unproductive energy, however, the faster rate of striking will require nearly 30 per cent additional per stroke, and nearly 50 per cent additional in the minute, assuming that the length of stroke, and of sliding, are the same in both cases.

Through the kindness of Dr Bourne with whom I have had much correspondence, and of the respective Presidents of the University Boat Clubs 1926 Mr C E Pitman (O U B C), and Mr G H Ambler (C U B C), I have at present, on loan, some of the cinematograph films of the University Crews at practice. I have spent a good deal of time in taking measurements from the films, under a microscope, with a view to analysis of the movements of crews and boats. So far as I have had time to deal with the measurements already taken there appears to be strong confirmation of the principles and calculations put forward in the two papers I have had the honour of reading to this Society.

GEOLOGICAL AND PETROLOGICAL STUDIES OF THE CALTON HILL (DERBYSHIRE) VOLCANICS

By S. TOMKEEFF

The massive white Carboniferous limestone of Derbyshire contains many relics of ancient volcanoes including volcanic necks, lava flows and intrusive masses. Of such Calton Hill (near Buxton) is a typical example. Its somewhat complex structure is revealed in the section of the road metal quarry. There we see stratified tuffs and agglomerates forming the volcanic cone and vesicular decomposed lava invaded by an intrusive fresh analcrite basalt. The invading basalt tore off and incorporated large masses of the lava and also penetrated between the lava and the underlying tuffs.

All the rocks composing this complex together with some rocks from the immediate vicinity have been subjected to a detailed chemical and microscopical study. Their principal features are as follows.

The tuffs and agglomerates are composed of fragments of vesicular lava (probably belonging to the lower lava flow) and limestone embedded in a fine grained pyroclastic material.

The lava (toadstone) is highly decomposed and the vesicles are filled up with a finely crystalline chlorite (Delessite) similar to that found in many other outcrops of the lava.¹ The lava of Calton Hill resembles the spilitic lava of Miller's Dale and probably represents an alkaline differentiate of the main mass of the erupted magma.

The fresh analcrite-basalt of Calton Hill is characterised by numerous inclusions of angular fragments of peridotite ("olivine nodules"). A comparison of chemical analyses

¹ S. I. Tomkeeff. On some Chloritic Minerals associated with the Basaltic Carboniferous Rocks of Derbyshire. *Min. Magazine*, 1926 Vol. XXI No. 116 p. 78.

suggests that this peridotite is a product of crystallisation-differentiation in the magmatic reservoir of the main body of the magma. This heavy magnesian differentiate probably crystallised under plutonic conditions in the volcanic vent and was subsequently broken up and incorporated into the analcite basalt in form of inclusions.

Besides peridotite inclusions this basalt contains numerous spherules of analcite. Chemical analysis of this basalt show that it is a normal sub alkaline basalt, and it is possible that the origin of analcite can be explained by the syntectic differentiation hypothesis of R. Daly. This supposes that the intruded basaltic magma absorbed a small amount of lime which led to the devolatilisation of the residual liquor and subsequently to the production of analcite the latter separating out in the form of colloidal globules.

The volcanic history of the Calton Hill complex can be divided into two periods.

In the first or *Ejective* phase the volcanic cone was formed and submarine eruption of lava took place.

In the second or *Intrusive* phase the basalt was intruded into the old volcanic vent causing the break up of the earlier peridotite plug and the formation of a laccolitic mass within the old cone.

These two phases of volcanic activity probably correspond to the two magmatic cycles of the hypotheses of radioactive melting of the basaltic substratum as suggested by J. Joly² and A. Holmes³.

A detailed account of this work is to be published elsewhere.

² John Joly The Surface-History of the Earth Oxford 1926

³ A. Holmes Radioactivity and the Earth's Thermal History Geologist Magazine 1925 Vol LXII pp 504, 529

THE GEOLOGICAL RELATIONS OF THE COAST SECTIONS BETWEEN TYNEMOUTH AND SEATON SLUICE

By R G ABBAS M.S. I WM HOPKINS M.S. PH.D

1 INTRODUCTION

The aim of this paper is to establish the stratigraphical horizons of the deposits exposed on the coast of Northumberland from the mouth of the Tyne to Seaton Sluice. These places are only some eight miles apart but the rocks exposed are greatly disturbed by numerous faults and thrust movements and are themselves so variable in character and thickness that the task of correlation is rendered extremely difficult.

A glance at the map of the coast will show that all the headlands consist of massive beds of sandstone in many cases further protected by reef like shelves of sandstone either projecting a fair distance out to sea or running more or less parallel to the coast line (*e.g.* Sharpness Point Brown Point Table Rocks St Mary's Island Crag Point Chaleys Garden and Seaton Sluice Point).

2 PREVIOUS WORK

Very little work appears to have been done on this particular section of the coast. The geological map of 1861 is fairly accurate as regards the faulting but does not attempt to show clearly the correlation of the deposits with the main Coal Measure Series of Northumberland and Durham.

The only previous attempt at a correlation due to S R Haslehurst³ in 1912 has been accepted generally. Mr Haslehurst did not describe the section further north than Crag Point and while his correlation can be accepted as far as the Brierdene fault the authors are forced to

dissent from the naming of the seams outcropping between this fault and Crag Point. It was thought that only one seam—the Grey Seam—outcropped in this portion of the section but evidence will be brought forward to show that this view is erroneous.

The correlation adopted in this paper is based upon two main factors —

- (a) A careful comparison of the lithological characters and sequence of the rocks exposed with those recorded in colliery workings adjacent to the coast between Blyth and North Shields
- (b) A comparison of the palaeontological horizons (mussel bands and plant beds) found in the coast section with those observed in the colliery workings during an investigation carried out by one of the authors.⁵

3 STRATIGRAPHICAL SUCCESSION AND GEOGRAPHICAL DISTRIBUTION

1 Recent and Glacial	Deposits of sand and boulder clay Sand dunes Blyth to Seaton Sluice Boulder Clay Collywell Bay Crag Point to Whitley Bay Cullercoats to Tynemouth Cliff
2 Permian	<ul style="list-style-type: none"> (a) Lower Magnesian Limestone Cullercoats Bay North Side of Ninety Fathom Dyke (b) Marl Slate Cullercoats Bay Tynemouth Cliff (c) Yellow Sands Collywell Bay (two outliers) Cullercoats Bay and Tynemouth Cliff
3 Middle Coal Measures	
Seventy Fathom Post	Charley's Garden Sandstone Seaton Sluice

Middle Coal Measure —Continued

High Main Mussel Band	In Blue grey shale on south side of the Seaton Sluice Dyke (basaltic)
High Main Seam	Three feet beneath foot of cliff and fifteen feet below the mussel band at Seaton Sluice
Grey or Metal Post	North end of Cullercoats Bay
Grey or Metal Coal	North end of Cullercoats Bay Walled up
Yard Coal	Collywell Bay cindered by Collywell Dyke Outcrops in dunes north of Seaton Sluice Sharpness Point south end of Long Sands Tynemouth
Bensham Post	Seaton Sluice Sandstone Crag Point Sandstone Brown's Point and Sharpness Point Sandstones
Bensham Seam	Crag Point Brown's Point and below base of cliff at Sharpness Point
Six Quarter Seam	Not present
Five Quarter Seam	St Mary's Island to Hartley Point
Table Rock Sandstone	Extends from the Low Main Seam to the Bensham Seam at Whitley Bay Between St Mary's Island and Crag Point it is divided into three sections by the Five-Quarter and Six-Inch Coal Seams
Low Main Mussel Band	Whitley Bay Foreshore north and south of Curry's Point

Middle Coal Measures, — continued

Low Main Seam	Below foreshore at Whitley Bay
	Represented by a three inch band of Black Shale five feet below the mussel band north and south of Curry & Point
Beaumont Post	Curry & Point and St. Mary's Island Sandstone Between the Low Main and Beaumont Seams

4 DESCRIPTION OF COAST SECTIONS*(a) Tynemouth to Whitley Bay*

As the greater part of this section has been described in some detail by several workers¹⁴, a general description only need be given here to bring out the relationship between this section and the section to the north.

Tynemouth or Pinney Cliff is composed of Permian deposits resting unconformably upon the Coal Measures, the cliff being capped by bivalved Middle Magnesian Limestone resting upon Lower Magnesian Limestone which becomes more and more arenaceous towards the base. Below these beds is the Murl Slate (3 feet) underlain by the Yellow Sands which are very variable in thickness and lie unconformably upon the reddish-tinged Coal Measures. At the extreme southerly end of the section is the well-known Tynemouth Dyke (basalt) a few yards from and parallel to the pier.

Near the top of the cliff to the north, which consists of alternating shales and sandstones dipping south, is the outcrop of the Yard Seam which, after traversing Sharpness Point, is faulted down to the shore at the north end of Tynemouth Short Sands. During recent excavations for the new Tynemouth Bathing Pool the Bensham seam was uncovered at a depth of some four or five feet below the base of the cliff on the north side of Sharpness Point.

SECTIONS OF THE NORTHUMBERLAND COAST FROM TYNEMOUTH TO WHITLEY SANDS

Diagrammatic Section from Tynemouth to the Ninety Fathom Dyke.

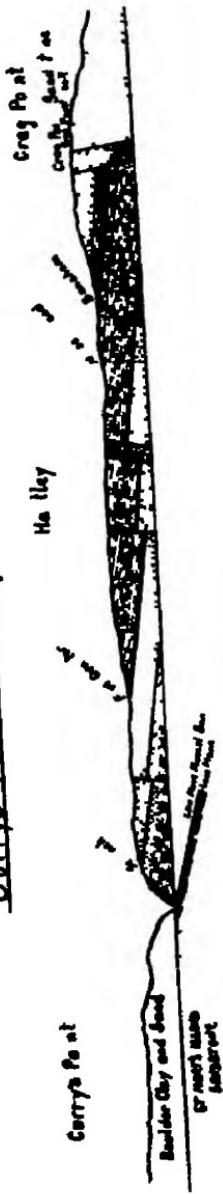


Collercoats Bay to Whitley Sands



SECTIONS OF THE NORTHUMBERLAND COAST FROM CURRY'S POINT TO SEATON SLUICE

Curry's Point to Crag Point



Crag Point to Seaton Sluice Point



From this point to the Smuggler's Cave the section is hidden by boulder clay and blown sand. At Kenner's Dene, near the centre of the Long Sands, a seam is present which the Geological Survey consider to be the Bensham, while at the north end, lying unconformably against the Magnesian Limestone—faulted down by the Ninety Fathom Dyke—is a seam thought to be the Low Main. Careful searching at this point has failed to reveal any trace of the Low Main Mussel band and the authors consider this seam to be either the true Bensham (*i.e.*, the same seam as is exposed in Kenner's Dene) or possibly the bottom section of the Bensham since the southerly dip is very gentle.

The Smuggler's Cave at the south end of Cullercoats Bay consists of greatly disturbed beds of Lower Magnesian Limestone which, together with the Marl Slate and Yellow Sands, are thrown against the Coal Measures by the Ninety Fathom Dyke heading north. These beds also rest unconformably upon the Coal Measures in the north end of the Bay where the Grey and the Yard Seams outcrop. These seams have been walled up but on the south side of Brown's Point a shale with perfect specimens of *Carbonicola* is found immediately overlying the Brown's Point Sandstone. During the recent dispute in the coal industry these seams were worked on the foreshore to the north of Cullercoats North Pier.

The sandstone forming this point is a massive brown sandstone just above the Bensham seam which outcrops in the middle of the cliff in the small bay between Brown's Point and the Table Rocks. The beds are dipping south and the seam, which shows a fine coal "leader," is dislocated by a small fault throwing north.

The remainder of the section has been worked out in great detail by Lebour and Smythe¹ who have brought forward indubitable evidence of thrusting and local unconformity. The Table Rock sandstone (extending from the Low Main to the Bensham seam) has been thrust horizontally over the underlying beds of shale, causing great disturbance in these and in the Low Main Mussel Band which is exposed occasionally for as much as half a

mile along the foreshore. A pebble bed above the disturbed strata is taken to mark a line of unconformity which occurs at a horizon corresponding to that of the Five-Quarter seam.

The Table Rock sandstone can be traced as far as the Convalescent Home after which the section is completely masked by boulder clay. During recent excavations in connection with the extension of the Whitley Bay promenade, the Five Quarter Seam (5 feet of good coal) was uncovered at several points to the North of the Home. About one hundred yards south of the Brierdene fault is a small dyke.²

(b) *Whitley Bay to Seaton Sluice.*

Between Whitley Bay and the south side of Curry's Point the deposits consist of blown sand and boulder clay; the Brierdene Fault with a downthrow of 150 feet to the north cannot be seen therefore at the surface. The foreshore around Curry's Point consists of a coarse sandstone, traversed by two small faults which die out seawards, which is continuous with the thick mass of sandstone comprising the whole of St. Mary's Island. This sandstone is at least eighty feet thick and is dipping rapidly inland at some six to eight degrees.

Towards the mainland this sandstone is overlain by ten feet of light blue sandy shale, two feet of very light coloured plastic seggar clay and a three-inch band of dense black shale. Above the black shale is a dark blue shale, in which is a prominent mussel band, the basal portion of which is highly ferruginous and full of *Carbonicola* shells.

The main portion of the mussel band contains an assemblage of *Carbonicola*, *Naiadites*, *Anthracomyia*, *Spirorbis*, and *Calamite* remains.

It bears a striking resemblance to the mussel band associated with the Low Main Seam of Northumberland and the Hutton Seam of Durham which have been shown to be the same seam. A characteristic feature of this mussel band is the presence of *Spirorbis*³ and *Spirorbis* has been found in both the Whitley mussel band and the mussel

band at Curry's Point. The shale and the mussel band are exposed on the shore to the south of Curry's Point and immediately north of the path to St. Mary's Island.

In the bay north of Curry's Point the dark blue shale is overlain by a sandstone five feet thick characterised by pronounced rectangular jointing similar to that of the Table Rocks sandstone at Whitley Bay. This sandstone extends along the shore as a flat table for a considerable distance and is followed in the cliff by a coal seam of six to twelve inches in thickness, fifteen feet of sandstone and a coal seam in two sections of two feet six inches.

From an examination of the shaft records of collieries situated near the coast this sequence indicates that the upper seam is the Five-Quarter, the underlying sandstones the equivalent of the Table Rock sandstone of Whitley Bay, the mussel band, the Low Main mussel band and the black shale (3 inches) the equivalent of the Low Main Seam.

This is borne out by the fact that in Northumberland the Low Main seam is very variable and in some cases is practically washed out.

The St. Mary's Island sandstone, on this reading, is below the Low Main seam and is the equivalent of the Beaumont Post which is well developed at East Holywell and Backworth Collieries some two miles inland. The Table Rock sandstone at Whitley Bay comprises all the sandstone between the Low Main and Bensham seams; in the area under consideration it is considerably thinner and is split into three sections by the "Six-Inch Coal" and the "Five-Quarter," the upper portion passing rapidly into sandy shales towards the north. The beds dip gently towards Hartley Steps Bay and are traversed by five small faults all throwing to the south.

Hartley Steps Bay.

At the south end of this bay a staple was put down through the sandstone table during the miners' strike of 1887 and the Low Main seam was reached at a depth of some twelve feet, the seam proving to be good coal four feet thick. The Five-Quarter seam passes under the foreshore

and the strata in the cliff consist mainly of grey shales with sandstone and ironstone bands. The Five-Quarter has recently been worked on the foreshore as far as the point opposite Hartley village and has proved to be a six feet seam of good quality. The shale contains a mussel band, comprised of *Carbonicola* shells and *Spirorbis*, immediately below which is a ferruginous band with typical cone-in-cone structure developed. The mussel band which is ferruginous and contains Kaolinite can be traced from the Hartley Steps to the Crag Point Fault where it is some five feet below a seam in two sections of two feet six inches.

This seam appears at the top of the cliff a little to the south of the Crag Point, the top section being overlain by a band of grey shale four feet thick followed by sandstone to the top of the cliff. It is thrown thirteen feet to the north by a fault which brings it near the base of the cliff at Crag Point. This seam must be the Bensham seam and not the Grey as has been assumed, since it is the next in the series to the Five-Quarter. Confirmation of this point is afforded by the presence of plant remains in the grey shale immediately above the seam, a conspicuous plant bed being a valuable characteristic of the Bensham seam and its equivalents in the Northern coalfield. The Bensham at this point is thrown down some eighty feet to the north by the Crag Point fault, since the Crag Point sandstone which is normally above the grey shale is brought down in contact with the seam. At exceptionally low water the Bensham seam can be seen some sixty yards from the foot of the cliff below the sandstone when the water is clear.

Crag Point to Collywell Bay.

The Crag Point sandstone is a light whitish-brown sandstone forming the high cliff from Crag Point to the south end of Collywell Bay where it is cut off by a fault. Since the Sharpness Point and Brown's Point sandstones are also between the Yard and the Bensham seams these three sandstones must be the same; an examination of colliery sinkings at Hartley and Holywell shows that the Bensham is overlain there also by a similar thick mass of

sandstone. At the south end of Collywell Bay the sandstone is overlain by dark blue shale and boulder clay, the blue shale containing abundant plant remains, chiefly *Calamites*.

From personal observation we have ascertained that the blue shale above the Bensham seam in the East Holywell Pit is crowded with *Calamite* stems, indicating that, in all probability, the shales are the same.

Collywell Bay.

Glacial, Permian and Coal Measure beds outcrop in the cliff section. The Coal Measure Series form a faulted syncline—the Crag Point sandstone at the south end dipping North and the Harley's Garden sandstone (considered by the authors to be, the Seventy Fathom Post) at the north end of the bay dipping South at a fairly high angle (12°). The fault some twenty yards north of the Collywell Dyke is considered by the Geological Survey to have a downthrow of thirty-six feet—a figure which the authors believe to be much too small for reasons to be discussed subsequently. Both the Collywell fault and the dyke can be traced right across the bay with a southward sweep, the fault apparently cutting off the northern face of the Crag Point sandstone.

The effect of the fault is to bring in the Yellow Sands of the Permian in two exposures at the top of the cliff in the centre of the bay and above the incline leading to the sands. They rest upon sandstone overlain by shales with lenticular beds of sandstone and are the most northerly exposures of the Permian series in Northumberland.

The magnitude of the Collywell fault is important in that it accounts for the presence of these two Permian outliers in the cliff.

The shale above the Crag Point sandstone contains a seam three feet six inches thick—the Yard seam—which outcrops in contact with the Collywell Dyke and has been converted to a prismatic cinder coal. The dyke has a faulted junction with the surrounding beds but apparently the throw of this fault is only a few feet to the south while

some fifteen yards north of the dyke is a small fault of eight feet throwing north.

To arrive at some idea of the magnitude of the Collywell fault it is necessary to study the strata exposed at the Seaton Sluice end of the section. The most northerly exposure is a thick mass of well-bedded sandstone dipping slightly inland; the individual beds exhibiting marked false bedding indicating a shallow water origin. It is traversed by two thin bands of shale, the upper of which dies out laterally, the base of the overlying sandstone containing a pebble band denoting a break in the deposition.

This sandstone extends to the sand dunes which cover the rest of the coast to Blyth and although no surface evidence indicates its horizon, this can be arrived at by comparison with colliery records near Hartley and Holywell. The Yard seam has been proved by borings below the dunes approximately along the line of the main coast road to Blyth.

At Holywell colliery some three miles south-west of Seaton Sluice the sandstone between the Yard and the Bensham is sixty-five feet thick, at Hartley sixty feet thick, while the Seaton Sluice sandstone is at least fifty feet thick.

Hence the Seaton Sluice sandstone dipping inland beneath the Yard seam is the equivalent of the three sandstones previously found to be at this horizon, i.e., the Sharpness Point, Brown's Point and Crag Point sandstones. Just south of the entrance to the Sluice it is terminated by a fault throwing south which has been estimated at seventy-eight feet, but from considerations given below the authors have found it necessary to increase the throw considerably.

On the downthrow side of this fault a seam three feet six inches has been proved a few feet below the base of the cliff overlain by a mass of shale at least fifteen feet thick. Immediately above this shale is a thin seam of eight to twelve inches and another fifteen feet of grey shale containing a mussel band of very prominent *Carbonicola* shells.

The authors believe the seam below the base of the cliff to be the High Main Seam for the following reasons:—

The horizon of the High Main seam can be determined by three characteristics—

- (a) its thickness—generally three to ten feet;
- (b) it is overlain by a sandstone usually of considerable thickness—the High Main Post; and
- (c) the sandstone is followed by a thin seam and from fifteen to twenty-two feet of blue or grey shale containing a mussel band.

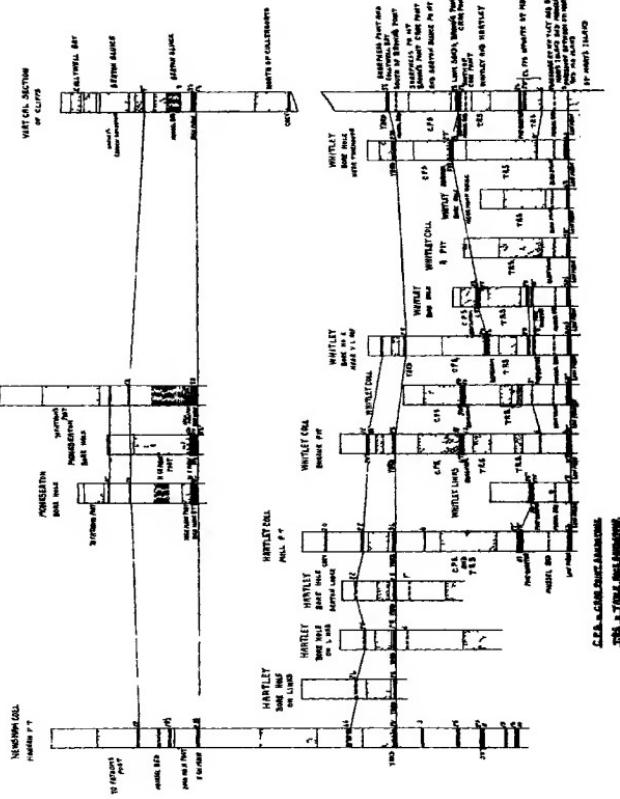
An examination of the colliery records shows that north of Backworth, the High Main seam is no longer a conspicuous seam of seven feet but has thinned to two feet to three feet six inches. Further this thinning is accompanied by a diminution in thickness of the High Main Post and its lateral passage into shale which is still overlain by a thin seam and dark shale with a mussel band.

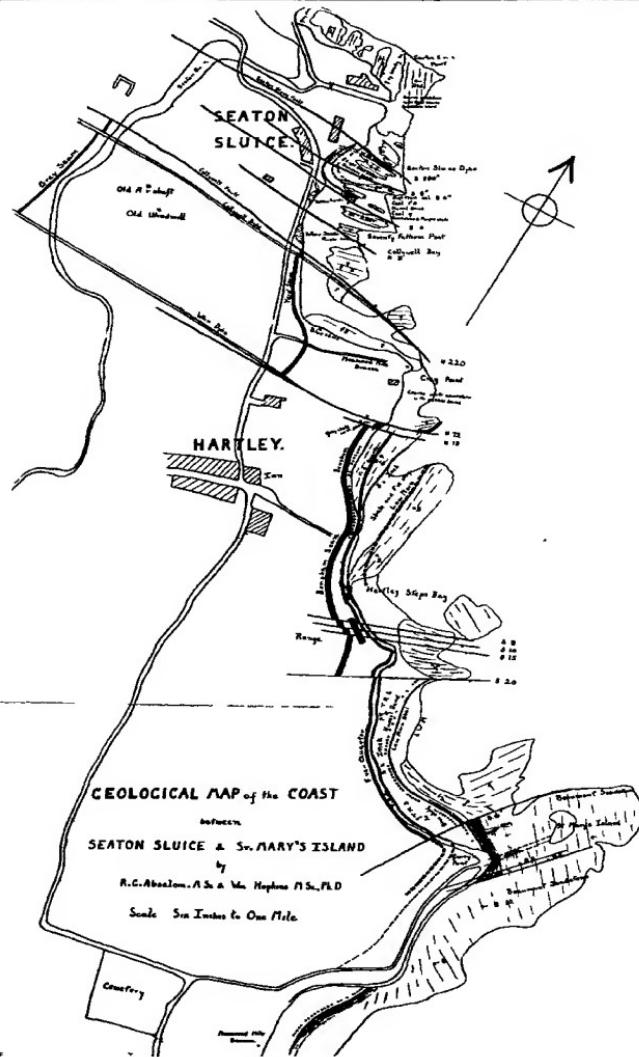
In Northumberland this shale is generally followed by another well developed sandstone—the Seventy Fathom Post. The Charley's Garden sandstone, therefore, is the bottom section of the Seventy Fathom Post, the mussel band is the High Main mussel band, and the seam just under the foreshore is the High Main seam. The interval between the seam and the mussel band is less than usual and the High Main Post has passed into shale.

Since the shale containing the High Main mussel band is found thrown against the sandstone underlying the Yard seam, the Seaton Sluice fault under discussion must be at least 180 feet instead of the 78 at present indicated on the Survey map (taking the average distance between the Yard and the High Main seams in the district).

The High Main beds are dipping south and are affected by two step faults which throw down the Charley's Garden sandstone to the shore. The Charley's Garden sandstone is a massive brown rock which forms the stack of that name some twenty yards from the cliff face; it is dipping south at

VERTICAL SECTIONS FROM NEWSHAM TO WHITLEY.





a very high angle (20°) and can be traced to the inclined road leading to Collywell sands. It then passes under the shore, and in the centre of the bay must commence to rise to the south until it reaches the fault first mentioned twenty yards north of Collywell Dyke.

In the Collywell cliff, this sandstone is overlain by shales and the upper sections of the Seventy Fathom Post on top of which the Permian Yellow Sands are deposited unconformably.

Since the Seventy Fathom Post is thrown down against the strata just above the Yard seam, and the average distance between these horizons in this district is 220 feet, it follows that the throw of the fault must be near this figure and not thirty-six as at present indicated.

The sandstones on each side of the fault bear a superficial resemblance to one another, but closer examination shows that they are decidedly different in character; on the south side of the fault the shale is pure, while on the north side it is thicker and is mixed with lenticular bands of sandstone.

Formation of Collywell Bay.

The two large faults of 220 and 180 feet are throwing north and south respectively so that Collywell Bay marks the position of a huge trough fault. These two faults converge inland and gradually die out so that the figures 36 and 78 feet are probably quite correct values of the throw in the colliery workings from which they must have been obtained. The structure of the bay, therefore, can be likened to a wedge which has dropped at the broad end, the intersection of the faults acting as a pivot, i.e., the Yard seam is continuous inland and is present at the coast on the north and south of the bay, while the High Main measures (which are mainly soft shales) have been let down to that level in the bay itself.

It is worthy of note that both of these large faults are accompanied by igneous dykes, indicating the tendency of intrusions to follow lines of great disturbance.

Evidence of Thrusting.

At the base of the Seventy Fathom Post just north of Charley's Garden, there are signs of a slight unconformity and thrusting in an east and west direction. Owing to the undercutting of an anticlinal section of this sandstone, striae at right angles to the coast can be seen clearly in the basal portion of the rock.

This thrusting movement is probably connected with the tilting of the wedge which was primarily responsible for the formation of Collywell Bay. As the faults in question have affected both Carboniferous and Permian strata it is probable that the thrusting is connected with the Post-Permian earth movements which have affected other portions of the North-East Coast, notably at Whitley Bay, Marsden and Ryhope.

5. CONCLUSIONS.

(a) The Coal Measure Series exposed in the sections are represented by some 500 feet of strata extending from the Seventy Fathom Post to the Beaumont sandstone.

(b) There are exposures of four main sandstones:

- (1) Seventy Fathom. Charley's Garden.
- (2) Between Yard and Seaton Sluice, Crag Point, Bensham seams. Brown's Point and Sharpness Point.
- (3) Between Bensham and Table Rock sandstone at Low Main seams. Whitley Bay. Curry's Point to Hartley.
- (4) Beaumont Sandstone. St. Mary's Island.

(c) The High Main Post, usually a persistent band in Northumberland, is absent at Seaton Sluice owing to rapid thinning and lateral replacement by shale.

(d) The fault in Collywell Bay bringing in the Yellow Sands has a much greater throw than appears on the map. It must throw to the north at least 220 feet. Similarly the Seaton Sluice fault must have a throw to the south of at least 180 feet.

Thus Collywell Bay is due to a large trough fault throwing down the soft shales of the High Main measures.

(e) There is evidence of thrusting in an east and west direction at the base of the Seventy Fathom Post at Seaton Sluice, which is probably connected with the Post-Permian earth movements which have affected other portions of the coast at Whitley Bay, Marsden and Ryhope.

The authors beg to thank Professor H. G. A. Hickling, D.Sc., of the Geological Department, Armstrong College, and Professor A. Holmes, D.Sc., of the Geological Department, Science Laboratories, Durham, for their interest and practical help during the preparation of this paper.

Note.—Scale of Const Sections $5\frac{1}{2}$ in. = 1 mile.

Scale of Vertical Sections 1 in. = 118 ft.

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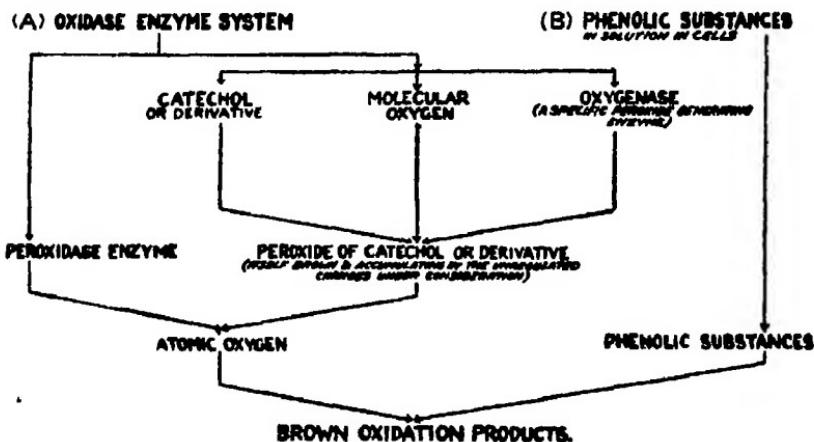
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PLANT DECAY AND SUBSEQUENT MINERALISATION.

PART I.—THE BROWNING OF DYING PLANT CELLS.

By MERION THOMAS, M.A.

Browning, which never occurs in healthy living cells of the higher plants, inevitably results when the components of A and B (see below) assemble. So it will occur when the protoplasm of cells of oxidase plants—for example, that of apple cells—disorganises either during the final phases of their normal senescence, or prematurely after mechanical injury, parasitic attack, or functional disturbance:—



These colour effects in oxidase plants probably record the last biochemical oxidations under the control of their dying protoplasm. After death, during desiccation, plant remains, even those of non-oxidase plants, may brown slightly by simple chemical oxidations. The dried remains of all plants finally become incorporated with the soil as complex mixtures of substances such as these brown non-nitrogenous highly oxidised aromatics, proteins, carbohydrates, organic acids, mineral salts, etc.

REFERENCE.

Onslow, *Biochem. Journ.*, Vol. XIV. (1920), Vol. XV. (1921).

PART II.—THE BEGINNING OF VEGETABLE DECAY.

By S. H. COLLINS, M.Sc.

After the enzymes of the plant have fulfilled their destiny and the plant tissues are dead, bacterial changes play a leading part in the chemistry of the dead plant tissues. Under natural conditions leaves fall on the soil and decay, and the practices of agriculture and horticulture assist this natural rate of decomposition. The simpler sugars are soon oxidised, leaving cellulose and the more resistant proteins. Rothamsted workers have shown that straw can be rotted into manure at a rapid rate and the author compared those results with the decomposition of pure cellulose in the laboratory. Nitrogen, phosphorus and potassium are essential bacterial foods and the humification of cellulose cannot take place in their absence. The rate of humification is closely connected with the amount of nitrogen supplied. Some bacteria can obtain nitrogen from the air, but they require more soluble forms of carbohydrates than cellulose. There is a tendency to approach an equilibrium of organic matter which, irrespective of origin, contains 2 per cent. of nitrogen when dried.

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PART III.—THE MINERALISATION OF PLANT RESIDUES.

By H. G. A. HICKLINE, D.Sc.

The ultimate conversion of plant residues into "mineral" fuel can be shown to follow very well-defined lines of chemical change. In spite of the great variety of plant materials which may enter into the composition of different peats, the bulk composition of such peats varies within only narrow limits. It therefore appears

that the early decomposition exerts a selective action, and that the "surviving" materials are the same in most cases.

A graphical examination of an extensive series of analyses of peats, lignites and coals of all kinds, shows that they have a remarkably linear distribution, such as can only result from chemical changes following similar lines in all cases. In the peats, the changes result in considerable elimination of hydrogen as well as carbon and oxygen. In the series of lignites and bitumenous coals the further change appears to result in the elimination of carbon and oxygen only, these being progressively extracted in the general proportion C : O₂. The highest degree of alteration, which gives rise to the anthracites is again characterised by extensive elimination of hydrogen. The nitrogen and sulphur appear to be little affected by the chemical changes after the early stages which convert the original materials into peat.

Fossil fuels are shown by the graphs to form a remarkably continuous series from the least changed peats to the most highly "carbonised" anthracites. It does not appear that there is any stage in the long series of changes at which the alteration was arrested, such as would be indicated by the exceptional frequency of coals of a given composition, with the possible exception of a small break between the bitumenous coal and anthracite groups. There appears to be no doubt at all that the composition of a fossil fuel is in the main dependent on the stage of chemical alteration as determined by the geological conditions to which it has been subjected, and is influenced in only a minor degree by the original vegetable composition.

THE HYDROLYSIS OF SALTS BY STEAM. (ABSTRACT.)

By P. L. ROBINSON, H. C. SMITH and H. V. A. BRISCOE

The action of low pressure superheated steam on the sulphates, phosphates, chlorides, bromides and carbonates of the alkaline earth metals at temperatures below 1,000° was investigated by passing steam at a carefully controlled rate over weighed quantities of material in a porcelain boat in a silica tube resistance furnace. The temperature was varied by altering a series resistance, and was measured with an accuracy of $\pm 5^\circ$ by a Platinum/Platinum-Rhodium thermocouple and a Paul millivoltmeter.

The sulphates and phosphates were stable below 1,000°.

The results obtained with the other salts show that in each case the stability under these conditions increases in the order: calcium, strontium, barium; whilst with the halide salts of these metals the stability increases in the order: iodide, bromide, chloride, fluoride.

The silica of the boat may play an active part in some of these reactions since in the case of the carbonates the surface of the porcelain was visibly attacked.

The lowest temperature at which appreciable hydrolysis occurs with the various compounds is given below:—

Calcium chloride, 425°. Calcium bromide, 848°.

Strontium chloride, 640°. Strontium bromide, 443°.

Barium chloride, 970°. Barium bromide, 640°.

Calcium carbonate, 440°.

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- Nov 9th — The Basic Principles of Thermodynamics By Dr J Morrow
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- " 10th — The Dimensions of Atoms By R G Luunon, M.A., M.Sc.
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- " 28th — Dielectric Problems with special reference to Cables" By Prof W M Thornton
- Dec 3rd — The Photo-E.M.F. in cells containing a Fluorescing Solution" By W Rule M.Sc.
- " " The Hydrolysis of Salts by Steam By H C Smith, M.Sc.
- " 7th — Further Points in connection with the Theory of Rowing By F H Alexander, M.Sc.
- 14th — Some experiments on the Electrical Discharge in Gases" By J Taylor, M.Sc., Ph.D.

1926

- Jan 19th — 'Torsional Oscillation' By G R Goldsbrough, D.Sc
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- " " "Plankton of the River Tyne" By Miss Jorgensen, M.Sc
- " 11th — "Sex and Parthenogenesis" By Dr J W H Harrison and A D Peacock, M.Sc
- " 12th — "The Browning of Dying Plant Cells" By M Thomas, M.A
- " " "The Browning of Plant Substance after Death" By S H Collins, M.Sc
- " " "The Changes from Peat to Anthracite" By Prof H G A Hickling
- Apr 27th — "The Examination of X-rays by the Method of Cloud Photography" By O Derbyshire, M.Sc
- May 7th — "Some developments of Operational Calculus" By Rev. F H Jackson, Sc.D
- " 27th — "Geological and Petrological Studies of the Calton Hill (Derbyshire) Volcanics" By S Tomkiesoff
- " " "The Geology of the Coast between Seaton Sluice and Tynemouth" By R G Abasalom, M.Sc., and W. Hopkins M.Sc., Ph.D.

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University of Durham Philosophical Society

APPLICATIONS OF SPECTROSCOPY TO MOLECULAR PROBLEMS

By PROF W E CURTIS, D.Sc.

The regularities discernible in the arrangement of spectrum lines are of two main types, which are usually designated line series and band series. The latter, with which we are here concerned, are as a rule more easily recognized than the former, on account of the occurrence of "heads," where the lines crowd closely together; on the other hand their structure is much more complex, and overlapping of several bands is apt to render their detailed analysis a very difficult and laborious task. This complexity is not without its compensations, however, for by the dawning light of theory we begin to perceive in each phase of it a new means of access to knowledge previously unattainable. Much has been learnt of the atom from the study of line series, but much more may be learnt of the molecule from the study of band series. It is proposed to survey briefly some of the results of work in this field.

In the first place we may consider the features which are common to both line and band series. The normal atom, by absorbing energy, may be put into a variety of temporarily stable ("excited") states, which differ from each other in respect of the configuration of the electrons. These states fall naturally into groups or sequences which have well defined characteristics, and simple rules may be formulated for the purpose of describing the transitions which are found to take place between them. The frequency of the radiation emitted as a result of such a transition is determined solely by the difference in the energy values of the states involved. In the case of a molecule also excitation by electron displacement can occur, but the absorbed energy may be stored

in other ways as well, so that the variety of excited states is much greater. It is still true, however, to say that the greater part of the energy emitted is derived from the electrons, so that the location in the spectrum of a band is primarily determined by the same process as for a series line, but it is only quite recently that an exact correspondence between the two cases has been established. That is to say, it now appears possible to group the electronic states of molecules into sequences on precisely the same lines as for atoms, and therefore to apply to them the methods of interpretation which have proved so remarkably fruitful in the latter case. It is even possible in some cases to recognize a "corresponding atom," that is to say, an atom in which the arrangement of outer electrons is identical with that of the molecule in question.

But the energy of a molecule, although predominantly electronic in character, is not entirely so. The remainder may be regarded as partly due to the rotation of the molecule and partly to the vibration of the atomic nuclei within it. Each of these factors is concerned in the process of emission; conversely, the analysis of a band spectrum provides us with information concerning them. They are not entirely independent factors, but since their mutual influence is relatively small it is permissible to consider them separately.

The most striking feature of a band spectrum, the ordered arrangement of lines which reaches its climax, as it were, in a head, may be characterized as rotation structure. Were the rotation of the molecule gradually to die away (as it does in fact tend to do as the temperature is lowered) the band would become steadily shorter and shorter, eventually dwindling to a single line when the molecule had ceased to rotate at all. Thus the extent of the band, and particularly the intensity distribution within it—a more definite quantity—provides an indication of the temperature of the radiating gas, or, more strictly, of the effective temperature of the radiating molecules, which is not necessarily the same thing. Further, the spacing of the lines, if they have been numbered off correctly, gives at once

the moments of inertia of the molecule before and after the act of emission. In the case of diatomic molecules of known constitution the distance apart of the nuclei is then directly obtainable. In cases where the constitution is uncertain (and these are not infrequent) the question can often be settled by a comparison of the band structure with that of molecules of known constitution. In this way several long standing controversies have been settled and a number of new molecules have been discovered (e.g., He_2 , and many metallic hydrides).

Turning next to the manner in which the bands themselves are arranged, we find regularities of a somewhat similar character but of fundamentally different origin. These are determined by the vibrations of the nuclei within the molecule, and the vibration frequencies can be deduced immediately if the numeration of the successive bands can be correctly fixed. A closer investigation of this "vibration structure" furnishes precise information concerning the force binding the nuclei and its dependence on their distance apart. It is in the vibration structure, too, that we find the most pronounced spectroscopic evidence of the existence of isotopes, and there would seem to be a possibility of turning this to account where additional evidence as to quantitative isotopic composition is required (as in the case of boron).

Such are some of the ways in which the study of band spectra is contributing to our knowledge of the molecule. For the sake of clearness it has seemed desirable to confine these remarks to the subject of emission spectra in the optical region, but there are other lines of research, equally rich in interest and promise. Investigations of infra-red spectra, for example, and of absorption and fluorescence spectra have also led to results of great importance, and there is no doubt that spectroscopic methods in general are destined to play a leading part in the solution of many of the problems of the molecule.

THE CRYSTAL STRUCTURE OF IODOFORM

By J. F. WOOD M.Sc. A Inst P

CRYSTALLOGRAPHIC DATA

Hexagonal

 $a = c = 1.11084$ (Groth—Chem Krys)

Specific gravity = 4.08 (Kaye & Laby's Tables)

Laue photographs taken perpendicular to the basal plane show that iodoform has no plane of symmetry through the hexagonal axis (The crystals which are in the form of hexagonal plates are too thin to permit of Laue photographs being taken in any other direction). The crystal must therefore belong to one of the following classes C_6 (hexagonal axis only) D_6 (hexagonal axis with perpendicular dyad axes) C_{6h} (hexagonal axis with plane of symmetry perpendicular to it).

The spacing of the basal plane (0001) was found to be 3.75 Å. The (1011) faces were beautifully developed on some of the crystals used but no X-ray reflection could be obtained from them presumably on account of its feeble intensity. A rotation photograph of the (1011) showed a faint line corresponding to the spacing 4.66 Å. These two spacings lead to the conclusion that the unit cell contains two molecules.

The number of asymmetric molecules required to produce the symmetry of the classes C_6 , D_6 , C_{6h} are respectively 6, 12, 12. The symmetry of the molecule of iodoform must be therefore three or six fold. The type of six fold symmetry required for D_6 is a trigonal axis with dyad axes perpendicular to it and for C_{6h} a trigonal axis with a plane of symmetry perpendicular to it. On chemical grounds these two possibilities may be ruled out and hence it appears that the molecule of iodoform has only three fold symmetry i.e. a trigonal axis and the crystal belongs to the class C_6 .

Assuming there are two molecules in the unit cell the dimensions are found to be

$$a = 6.92 \text{ \AA}$$

$$c = 7.69 \text{ \AA}$$

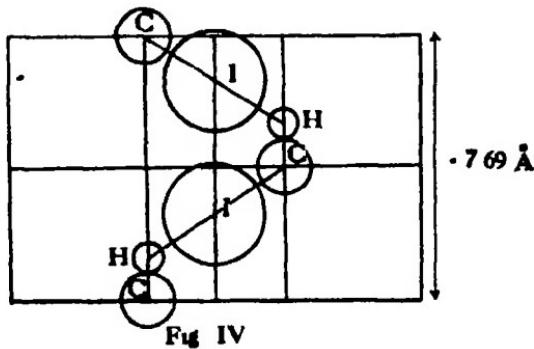
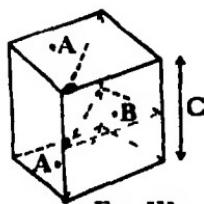
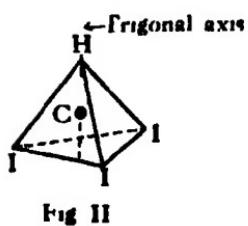
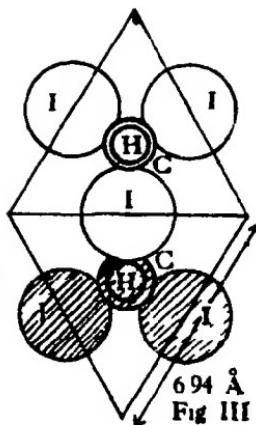
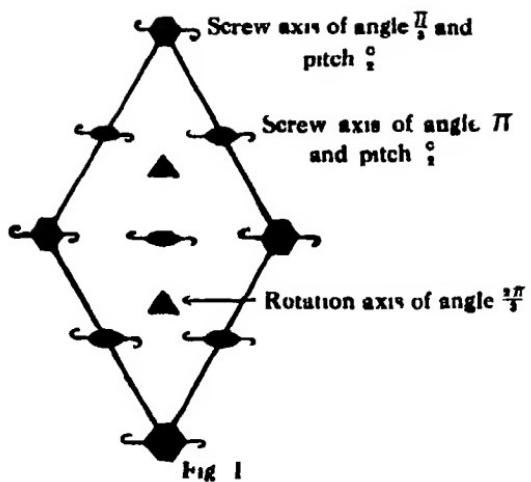
$$d_{0001} = 7.69 \text{ \AA} (3.75 \text{ \AA} \text{ observed})$$

$$d_{10\bar{1}1} = 4.75 \text{ \AA} (4.66 \text{ \AA} \text{ observed})$$

It is seen that the spacing of (0001) is half the calculated value. This indicates that the space group to which iodoform must be referred has screw axes parallel to the C axis and of pitch 3.75 \AA. Since the molecule of iodoform has a trigonal axis the space group must have trigonal axes also. The only space group fulfilling these two conditions is C_6 . (See Hilton, Mathematical Crystallography.) The arrangement of axes in this space group is shown in Fig 1.

The only arrangements of atoms which give a trigonal axis to the molecule of iodoform are the one shown in Fig 2 or the one in which the atoms all lie along a line. This latter is unlikely from the chemical point of view. The molecule must therefore be a tetrahedron with the carbon atom inside and the hydrogen and iodine atoms at the corners. The line joining the hydrogen and carbon atoms is the trigonal axis of the molecule. This axis must coincide with the axes  or Δ of the space group and this gives rise to two possibilities.

In the first case it is seen that the crystal is made up of lines of molecules whose trigonal axes lie along the crystallographic C axis. The molecules are alternately of type A and type B. B being obtained from A by a rotation of $\frac{\pi}{3}$ about the crystallographic C axis followed by a translation of 3.75 \AA along the same axis. A is obtained from B by an identical process. This fixes the relative orientations of the molecules in the crystal. If the iodine atoms of any molecule A touch the hydrogen of the next molecule B the structure is firmly held in the direction of the C axis. In directions perpendicular to this matters are otherwise. The iodines of neighbouring molecules do not come into contact unless the diameter of iodine is made much larger than 2.80 \AA, the usually accepted value.



The second alternative appears to be more satisfactory. In this case the structure appears, when viewed in the direction of the C axis, as a repetition of the pattern shown in Fig. III. The unshaded molecule represents the molecule at the top of the cell, i.e., A in Fig. IIIa, and the shaded one the molecule B which is half-way down the cell and obtained from A by rotation of $\frac{\pi}{3}$ about the C axis. The fit in this case is better. Fig. IV shows the arrangement of atoms in any plane parallel to the C axis, through the hydrogen, carbon and one iodine atom of any molecule. It is observed that the iodine does not quite fill the gap between the carbon of one and the hydrogen of a neighbourly molecule, but considering the fact that the spherical atom is only a rough approximation the fit is fairly satisfactory.

In conclusion the author takes this opportunity of expressing his thanks to the Research Committee of Armstrong College for financial assistance, and to Sir William Bragg for his kind interest and encouragement. The work was carried out at the Davy-Faraday Laboratory at The Royal Institution.

A RESIDUAL EFFECT IN THE ACTINIC ABSORPTION OF CHLORINE

By WILFRID TAYLOR, M.Sc., Earl Grey Memorial Fellow, and
ARTHUR ELLIOTT, B.Sc.

INTRODUCTION

In dealing with the photo-chemical union of chlorine with hydrogen, a method of investigation which has attracted little attention is that of subjecting the activating illumination to various perturbing influences, and observing the resulting change in the reaction initiated. Progress has been made chiefly in the direction of changing the frequency and the intensity. The latter has unfortunately been the subject of much diversity of opinion, and the former is bound up with it, inasmuch as experimental work has not yet been carried out in which the frequency, but not the intensity, has been varied.

It should, however, be possible to pursue investigations in a different manner, by using a strong beam of white light and a filter in which the activated substance itself is the filtering medium. Although we are thus using the integrated effect from a whole wave-band, yet the composition of the emergent light may be varied in a known manner by altering the absorption spectrum, and an analysis of the results might possibly bring fresh evidence to bear on the problem of molecular activation. The first experiment which suggests itself is to alter the composition of the light simply by increasing the equivalent thickness of the absorbing medium.

In the experiments to be described, the procedure was to permit hydrogen and chlorine to unite in a system in which the velocity of union could be determined under the influence of a beam of white light passing through a filter of chlorine of which the concentration could be altered in a known manner.

EXPERIMENTAL WORK

The rate of combination of hydrogen and chlorine under the influence of light may be determined by several methods, but the actinometer arrangement of Bunsen and Roscoe, subsequently used by Burgess and Chapman,¹ was considered to be the most suitable, since it enables the whole course of the reaction to be followed. In principle, the actinometer consists of a bulb, containing a little water to absorb the HCl formed, in communication with a narrow bore index tube so that the contraction of the gas volume may be followed by the movement of a liquid indicator. Side tubes with stopcocks serve to admit and extract the gas at will. The apparatus used was cleaned with the usual cleaning fluids many times in succession, and finally a little distilled water was introduced, so that a small surface was offered at the bottom of the bulb.

The gas mixture was prepared by the electrolysis of pure concentrated hydrochloric acid. The chief drawback to this method is the evolution of oxygen at the anode as the concentration of the acid falls,² to overcome this, some workers have used large quantities of acid and in the present experiments a glass chamber holding 2½ litres was employed. The electrodes, together with two glass tubes, passed through a stopper, sealed in and protected from the action of the chlorine by "picein" wax. Before commencing operations, a stream of chlorine gas was led through the whole apparatus for several hours in order to saturate all the liquids, and to remove all traces of air. The electrolysis was then commenced, and the mixed gasses were allowed to pass for several more hours the bulb of the actinometer being strongly illuminated by an arc lamp at the same time. The anti-catalysts were thus attacked by the activated chlorine, and removed from the system.

The reaction system was immersed in a large thermostat bath consisting of a tank of 20 gallons capacity fitted with a port-hole in one side through which light could be passed. The bulb was only a centimetre from the port-hole, so that the light absorbed by the water was negligible.

The illumination was provided by a Pointolite lamp. After having been rendered parallel by a lens, the light passed through a shutter then through the filter tube and finally through the port hole.

EXPERIMENTAL PROCEDURE

As it was found that the sensitivity of the mixed gases varied enormously during the course of a day the following procedure was adopted:

Typical Reaction Velocity Curves

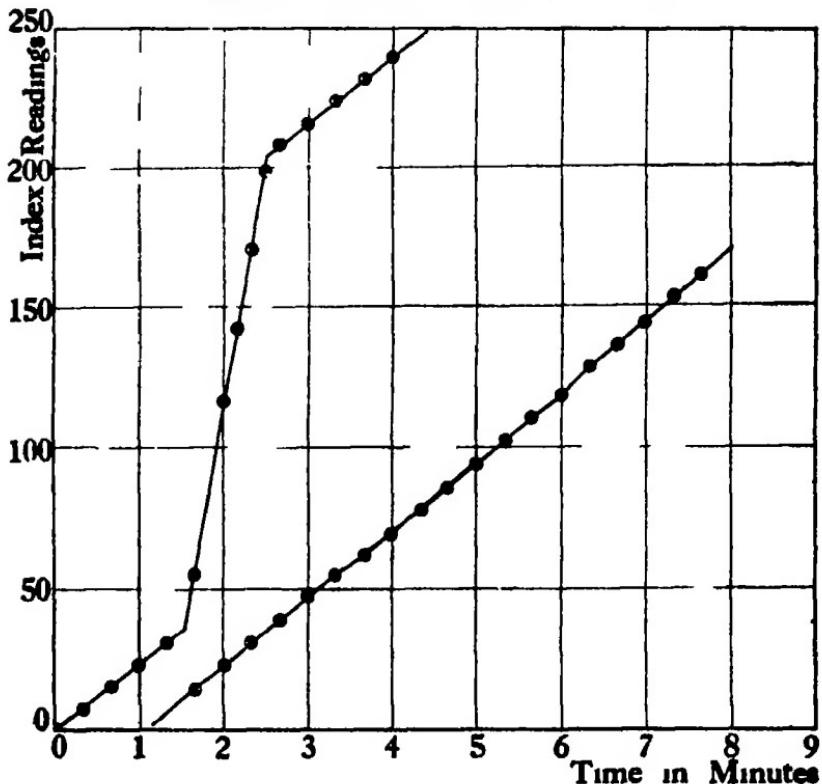


FIG. 1

The velocity of the reaction under the illumination from a lamp kept at a fixed distance from the actinometer was

measured by determining the rate of movement of the index along the capillary tube. Then this standard lamp was switched off, and the velocity under illumination from the Pointolite lamp was measured in the same way. Finally, the reaction velocity under the standard lamp was again measured as a check. The results of a typical measurement are shown in Fig. 1.

The velocity of reaction under the illumination from the Pointolite lamp relative to that produced by the standard lamp was then measured, and in all cases, this "relative

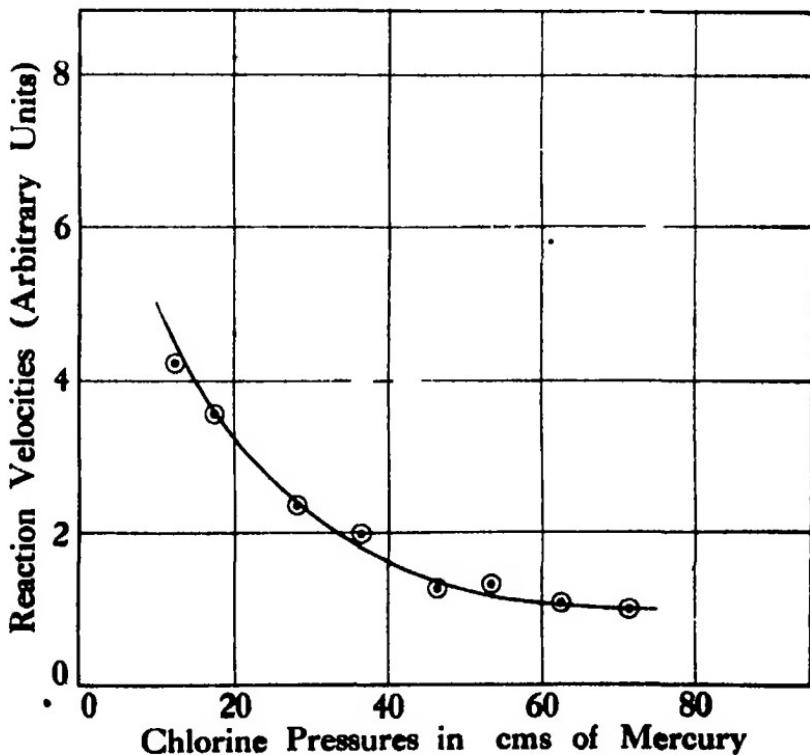


FIG. 2.

"reaction velocity" was measured, and by this means, the results were made independent of the sensitivity of the mixture of hydrogen and chlorine.

The procedure was repeated with various concentrations of chlorine in the filter, and so the effect of increased amounts of absorbing material on the velocity of reaction was determined.

The first experiments were carried out with a filter of chlorine gas contained in a tube provided with glass-end plates sealed on with "picin" wax. The tube was in communication with a cylinder of chlorine, a filter pump, and a manometer, so that the amount of chlorine in the filter could be varied in a known manner, the reaction velocity produced by the light passing through it being determined at the same time. In these experiments the tube was 45 cm long, the maximum pressure being atmospheric.

FIRST RESULTS

The results are shown in graphical form in Fig. 2, and are set out in Table 1 below. In this curve it will be seen that the reaction velocity ceases to fall off rapidly as atmospheric pressure is approached, and is not of exponential form.

TABLE 1

Temp of gas 18° C

Tube 45 cm long

Pressure of chlorine in filter tube in cm of Hg	Mean reaction velocity relative to reaction velocity with standard lamp
32 0	3 56
46 4	1 23
62 4	1 06
17 4	3 53
53 4	1 42
28 0	0 99
36 4	1 98
12 4	4 22

LATER METHODS

It was sought to obtain additional confirmation by using a greater concentration of chlorine in the filter, and in order to do this two methods were employed. In the first method, a solution of chlorine in carbon tetrachloride was employed as the filtering medium. This liquid was selected because it is chemically inactive with respect to chlorine, and could therefore be used without fear of any reaction with the chlorine even under intense illumination.

In the place of the tube of chlorine gas, a plane walled glass cell was employed, the light having to pass through a depth of 3 cm. of liquid. This cell was equipped with a closely fitting glass cover to prevent evaporation since the solution was very volatile. By this means we were able to pass the beam of white light through a quantity of dissolved chlorine, and to measure the velocity of the reaction produced by the light.

A saturated solution of chlorine was made up in the first place by passing a stream of chlorine from a cylinder through a tower of pure carbon tetrachloride. To obtain lower concentrations of chlorine, additional quantities of carbon tetrachloride were added to this stock solution. Unfortunately, these solutions, especially those near the saturation point, were very unstable owing to rapid evaporation, and it was found to be quite impossible to rely on adding known quantities of the diluting agent, hence it was necessary to estimate the strength immediately after removing the cap of the filter cell at the end of an exposure. For this purpose, a measured portion was transferred to a beaker, and shaken with excess of aqueous solution of potassium iodide. The iodine liberated in the water layer was then titrated with sodium thiosulphate, and the shaking continued until all the chlorine had passed from the tetrachloride into the water.

Another source of trouble lay in the tendency of some of the stronger solutions to become turbid, presumably owing to the evolution of chlorine in the body of the liquid.

The turbidity could be removed by filtering, and was always looked for carefully. In any case, it may be observed that a cloudy liquid would decrease the intensity of the light transmitted, and so operate against the residual effect under investigation. The results of these experiments are given in Table 2, and are shown graphically in Fig. 3.

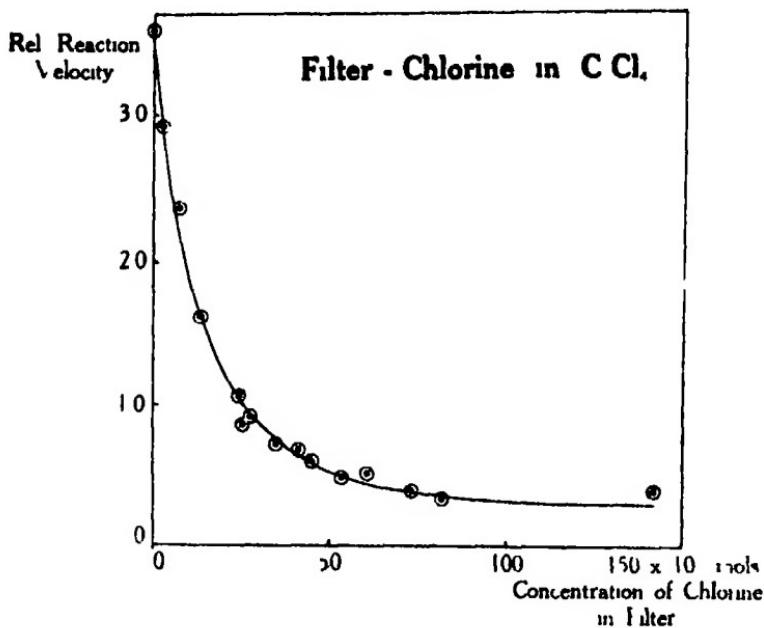


FIG. 3

The second method of increasing the concentration of the chlorine in the filter consisted in employing a longer tube (150.5 cm.) of gaseous chlorine in place of the cell. The gas supply, pump, and manometer were the same as in the previous experiments with the shorter tube. The effect of using a longer tube was, in fact, simply to extend the curve given in Fig. 2 to regions of greater equivalent pressures. The results of these experiments are given in Table 3 and in Fig. 4.

TABLE 2

(a)	(b)	(c)
0.0	0.0×10^{16}	3.66
78.0	142.1 "	0.39
43.1	73.5 "	0.54
45.1	82.0 "	0.33
40.3	73.2 "	0.39
33.4	60.7 "	0.51
29.3	53.3 "	0.48
24.8	45.1 "	0.60
22.7	41.3 "	0.68
19.3	35.0 "	0.72
15.3	27.8 "	0.92
14.1	25.7 "	0.86
13.3	24.1 "	1.06
7.3	13.2 "	1.62
4.3	7.7 "	2.38
1.5	2.76 "	2.96

TABLE 3

(a)	(b)	(c)
0.0 c.m. Hg.	0.0×10^{20}	1.24
75.0 "	40.1 "	0.05
66.7 "	35.7 "	0.06
57.7 "	30.9 "	0.05
46.3 "	24.8 "	0.06
34.5 "	18.5 "	0.12
25.9 "	13.9 "	0.19
23.9 "	12.8 "	0.22
21.0 "	11.2 "	0.24
15.0 "	8.0 "	0.28
14.3 "	7.6 "	0.34
7.8 "	4.2 "	0.46

In Table 2, (a) is the number of ccs. of N/10 sodium thiosulphate required to titrate 5 cc. of chlorine solution; in column (b) is given the number of chlorine molecules

actually interposed per square centimetre of cross-section of the beam in column (c) is the "relative reaction velocity" produced in the actinometer.

In Table 3 (a) is the chlorine pressure as read by the manometer (b) and (c) are as in Table 2

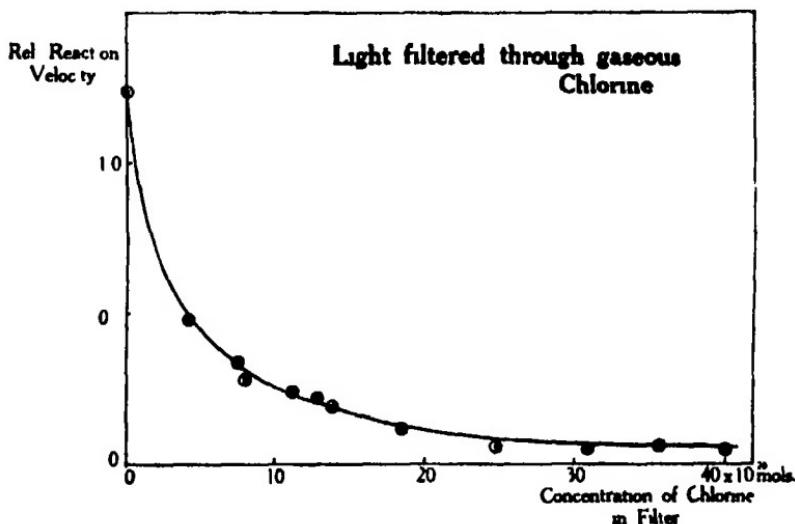


FIG. 4

CONCLUSION

All the curves obtained so far, although exhibiting certain differences as yet unaccounted for, agree in showing a "residual effect," that is to say, the light, after passing through large concentrations of chlorine, is still capable of activating chlorine. From an inspection of the curves, it appears that certain types of radiation present in ordinary light, are only feebly absorbed by chlorine, and, yet, are able to give rise to an appreciable amount of activation. It is claimed that these results, whilst at present rather of a qualitative nature, indicate that, by the use of this method, some information may be gained regarding the activating power of the feebly absorbed frequencies. Further work is at present in progress.

The authors wish to record their appreciation of the facilities and assistance afforded them by Professor G. W. Todd.

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- ² Chapman and MacMahon, *Journ. Chem. Soc.* **95**, 135, 1909.
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Q INTEGRATION

By REV F H JACKS M A Sc D

INTRODUCTION

The object of this paper is to set forth some possible developments of analysis by means of a certain operation which the writer terms q Integration. The operation is interesting principally because of its powers in effecting transformations of the q Functions as they are termed viz the series and products which are fundamental in the Jacobian theory of elliptic functions and in the theory of the theta functions. These series are of great interest also in the theory of partitions and divisions of numbers and were first used by Euler for this purpose. They were afterwards the subject of memoirs by Gauss, Clausen, Jacobi, Heine and others.

In the development of the theory all writers make use of the difference

$$\phi(z) - \phi(qz) \quad \Delta\phi(z)$$

The present writer varies this somewhat by using a difference quotient

$$\frac{\phi(x) - \phi(qx)}{x - qx}$$

It is noteworthy that while the difference operation has been so extensively and effectively used little has been done in the use of the reverse or inverse of this operation. By analogy this is as though in ordinary analysis mathematicians had limited themselves to $\frac{d}{dx}$ and neglected the integral \int . In practice it has been found that \int is the fruitful operator.

In the *Quarterly Journal of Mathematics* No 163 1910 the writer dealt with one or two special cases of the reverse operation showing such parallel forms as

$$\int_{-\infty}^{\infty} \frac{x^{a-1}}{1+x} dx = \frac{\pi}{\sin \pi a} \quad \sum_{n=0}^{\infty} \frac{x^{a-1}}{1+q^n} d_q x = \frac{\Gamma_q'(1)}{\Gamma_q(\lambda a)}$$

in which Γ_q denotes the writer's basic gamma function and $\sigma_q(\lambda x)$ a sigma function of Weierstrass' notation, the two integrals being coincident for the limit $q \rightarrow 1$.

NOTATION.

The notation is as follows:

$$\Delta \phi(x) = \frac{\phi(z) - \phi(qx)}{z - qx}$$

$\Delta^{-1} \phi(x)$ is denoted $\int \phi(z) d(qx)$

It is immediately obvious that when the functions under operation are differentiable or integrable, then for limit $q \rightarrow 1$,

$$\Delta \phi(x) \text{ becomes } \frac{d}{dx} \phi(z)$$

$$\Delta^{-1} \psi(x) \dots \int \psi(z) dz$$

In q-function theory, when n is a positive integer,

$$(1+x)(1+qx)(1+q^2x) \dots (1+q^{n-1}x) = (1+x)_n \quad (i)$$

takes the place of

$$(1+x)(1+x) \dots \text{to } n \text{ factors } (1+x)^n.$$

When n is not a positive integer the product (i) is replaced by a well-known infinite q-product

$$\prod_{r=0}^{\infty} \frac{(1+xq^r)}{(1+xq^{r+n})}$$

We note that symbolically if

$$q^{\theta'} \phi(x) = q^{\frac{\theta}{\theta'}} \phi(x) \quad \phi(x) - \phi'(qx)$$

$$(q^{\theta'} - 1) \phi(x) = \phi(qx) - \phi'(x)$$

so that by reversing the operation or inverting the operator,

then $\frac{q^{\theta} - 1}{qx - x}$ operating on any function is equivalent to the operator Δ and $\frac{qx - x}{q^{\theta} - 1}$ is equivalent to $\int d(qx)$; and in

the limit $q \rightarrow 1$ (if the functions are integrable) we find that

$\int d(qx)$ becomes $\int dx$

We note that just as

$$x(\theta + \alpha)(\theta + \beta)y - (\theta)(\theta + \gamma - 1)y = 0 \quad (ii)$$

is a linear differential equation one of whose particular solutions is the hypergeometric series $F(a, \beta, \gamma; x)$, so when

$[\theta + \alpha]$ denotes $(1 - q^{\theta + \alpha})/(1 - q)$ we find

$$x[\theta + \alpha][\theta + \beta]y - [\theta][\theta + \gamma - 1]y = 0 \quad (iii)$$

as the q differential equation of the Heinean Series

$$1 + \frac{(1 - q^\alpha)(1 - q^\beta)}{1 - q(1 - q^\nu)}x + \frac{(1 - q^\alpha)(1 - q^{\alpha+1})(1 - q^\beta)(1 - q^{\beta+1})}{(1 - q)(1 - q^2)(1 - q^\nu)(1 - q^{\nu-1})}x^2 + ad inf$$

and associated series

The whole theory of the ordinary hypergeometric series and the differential equation associated with it has its exact parallel in these q forms. The methods of Frobenius for solving (ii) have exact parallels in case (iii). I have dealt with this in the *American Journal of Mathematics*, Vol XXXII, No 4, so make reference only to that work in this paper.

I.

The following may be of interest and perhaps stimulate some student of mathematics to develop the theory further. Especially I would suggest much likely development by q -Integrals in the case of the basic Bessel functions¹

¹ Proc Lond Math Soc, 1904 Trans RSE, 1905

From the obvious difference theorem

$$\Delta \mu_x \nu_x = \frac{\mu_{qx} \nu_{qx} - \mu_x \nu_x}{qx - x} - \mu_x^! \nu_x + \mu_{qx} \nu_x^!$$

we see that

$$\int \mu_x^! \nu_x d(qx) = \mu_x \nu_x - \int \mu_{qx} \nu_x^! d(qx)$$

Applying this to such a product of functions as

$$F(-ax) x^{n-1}$$

where $E(-ax)$ is the fundamental q-series

$$1 + \frac{ax}{[1]} + \frac{a^2 x^2}{[2]!} + \frac{a^3 x^3}{[3]!} + \dots + \frac{a^n x^n}{[n]!} +$$

or its product equivalent

$$\frac{1}{\{1-x(q^1-1)\}\{1-qx(q-1)\}\{1-qx(q^2-1)\}}$$

since $[n] = (q^n - 1)/(q - 1)$

we get by q-integration by parts

$$\int E(-ax)x^{n-1}d(qx) = \frac{x^n}{[n]}E(-ax) + u \frac{q'}{[n]} \int E(-ax)x'd(qx)$$

Taking this between the limits 0 and ∞ , and noting that the term $\frac{x^n}{[n]}E(-ax)$ vanishes for both limits, it is obvious that

$$\int_0^\infty E(-ax)x^n d(qx)$$

can define a function satisfying a q-difference equation

$$\phi(a, n+1) = \frac{1}{aq}[n]\phi(a, n)$$

Such functions I have called basic gamma functions,¹ written $\Gamma_q(a, n)$ and given product expressions for them

The function in the case $a=1$ is $\Gamma_q(n)$, and further when $q \rightarrow 1$, is $\Gamma(n)$

¹ Proc Roy Socy, Vol 74, 1904

II CHANGE OF VARIABLE

The question of change of variable arises very early in the manipulation of integrals. Just as in the case of ordinary integration, so here, simplification is often effected by a change of variable under the sign of integration

The change in the case of q-integrals is, however, not so simple as in the ordinary case. Indeed possible changes are very limited, and I have reason to think that the only possible change is that of replacing x in a function

$\phi(x)$ by ξ where $x^n = \xi$. but even so many interesting

theorems arise. Consider

$$\sum \phi(x^n) d(qx) \dots \dots \dots \quad (iv)$$

putting $x^n = \xi$.

Now a change of variable involves also a change of base, since in the operations Δ and \sum we have qx substituted for x before taking differences. Let us suppose that Q is the new base required when the above substitution is made.

This gives, since $\Delta x^n = (n)x^{n-1}$

$$(n)x^{n-1} d(qx) - d(Q\xi)$$

and the integral

$$\sum \phi(\xi^n) d(Q\xi)$$

is transformed into

$$\sum \phi(\xi) \frac{1}{(n)} \xi^{\frac{1-n}{n}} d(Q\xi) \dots \dots \dots \quad (v)$$

Then if $\phi(\xi)$ is a function capable of expansion in a power series (Laurent) it is easily seen that to obtain the equivalence of (iv.) and (v.) Q must necessarily be q^n .

We thus see that when a variable x is replaced by ξ it is necessary in q -integration to replace the base q by q^n .

By this transformation we find that

$$\sum_0^\infty E(-a^2 x^2) d(qx) = \frac{a^{-2}}{(2)} \Gamma_{\alpha^2} \left(\frac{1}{2} \right)$$

corresponding to

$$\int_0^\infty e^{-a^2 x^2} dx = \frac{\sqrt{\pi}}{2a^2}$$

Similarly, we may show that

$$\sum_0^\infty E(-ax) x^{n-1} d(qx) = \frac{1}{a(n)} \Gamma_0 \left(\frac{n}{a} \right)$$

where $Q \equiv q^n$

$$a(n) \equiv a(1-q^n)/(1-q)$$

We note that in q -integration when the variable under the sign of integration is changed not only must the base of differences be changed but as in ordinary integration the limits also.

The q -definite integrals representing the solutions of q -differential equations for hypergeometric series with 5 elements or higher number of elements have been obtained

(*American Journal of Mathematics*, Vol. XXXII, No. 4). I refer to that paper for such results.

III.

It will suffice to give here a set of examples of simple q-integrals.

$$\sum_{\circ}^{\infty} \frac{1}{1+x} d(qx) = x - \frac{x^2}{[2]} + \frac{x^4}{[3]} - \dots$$

$$\sum_{\circ}^{\infty} \frac{1}{1+x^2} d(qx) = x - \frac{x^3}{[3]} + \frac{x^5}{[5]} - \dots$$

$$\sum_{\circ}^{\infty} \frac{1}{1+x^4} d(qx) = x - \frac{x^5}{[5]} + \frac{x^9}{[9]} - \dots$$

These series are perhaps more easily recognized in the forms

$$\frac{r}{1-q} - \frac{r^2}{1-q^2} + \frac{r^3}{1-q^3} - \dots$$

$$\frac{x}{1-q} - \frac{x^3}{1-q^3} + \frac{x^5}{1-q^5} - \dots$$

etc., well known from Jacobi's "Fundamenta Nova," and also of great interest in the theory of factors of numbers.

We can calculate numerically

$$\sum_{\circ}^1 \frac{\log x}{1-x} d(qx)$$

for this integral can be shown to be

$$(q-1) \log q \left\{ \frac{1}{8} \frac{\theta_4^{(1)}(0)}{\theta_4(0)} + \frac{1}{24} \frac{\theta_1^{(1)}(0)}{\theta_1(0)} + \frac{1}{24} \right\}$$

$$\text{so } \sum_{\circ}^{\sqrt{q}} \frac{1}{1+x^4} d(qx) = (1-q) \frac{\operatorname{sn}(\frac{\pi}{4})}{2\pi} K_K$$

in theta function notation. (Cf. Whittaker and Watson, "Modern Analysis.")

IV GENERALIZATION OF BERNOULLI'S THEOREM

I point out that from John Bernoulli's theorem

$$\int \phi(x) d(qx) - x\phi(x) = \frac{x^2}{2} \phi'(x) + (-) \int \frac{1}{n!} \phi^{(n)}(z) dz$$

has a simple parallel

$$\sum_0^x \phi(x) d(qx) = \phi(x) - qx \frac{x^2}{[2]} \phi'(x) + (-) q^{n(n+1)/2} x \sum_{[n]}^x \phi^{(n)}(z) d(qz) \quad (vi)$$

where $\phi^n(x)$ denotes the n^{th} successive q difference $\Delta^n \phi(x)$

This theorem gives at once a well-known transformation in theta functions

$$\frac{a}{1-q} + \frac{a^2}{1-q^2} + \frac{a^3}{1-q^3} + \frac{a}{(1-a)(1-q)} - \frac{a^2 q}{(1-a)(-aq)(1-q)(1-q^2)} + \quad (vii)$$

This comes from putting $\phi(x) = \frac{1}{1-x}$ in (vi)

If we put $\phi(x) = \frac{1}{(1-x)(1-qx)}$

$$\text{or } \phi(x) = \frac{1}{(1-x)(1-qx)(1-q^2x)} \text{ etc}$$

we have an unlimited number of theorems of the type (vii) which appear first in Jacobi's 'Fundamenta Nova'

The writer would say that by taking

$$E_q(x) = 1 + \frac{x}{[1]} + \frac{x^2}{[2]!} + \frac{x^3}{[3]!} +$$

and defining $S_q(x)$ and $C_q(x)$ respectively as

$$\frac{x}{[1]} - \frac{x^3}{[3]!} + \frac{x^5}{[5]!} .$$

$$\text{and } 1 - \frac{x^2}{[2]!} + \frac{x^4}{[4]!} .$$

$$S(x) = \frac{E_q(ix) + E_q(-iz)}{2i}$$

$$C_q(x) = \frac{E_q(ix) - E_q(-ix)}{2}$$

Noting $\sum S_q(x) d(qx) = C_q(x) + \text{constant}$

progress might be made in the development of this theory. Constants which appear in the q-integration just as in ordinary integration are periodic function constants of what may be termed multiplicative periodicity, namely of the type

$$\sum \text{Exp} \left(\frac{2i\pi \log x}{\log q} \right)$$

satisfying a 'functional equation'

$$\phi(x) = \phi(qx) = \phi(q^n x) \quad (n \text{ an integer})$$

In conclusion, I point out that the object of this note is not so much to introduce new work by the writer as to indicate certain lines of research for students who might wish to undertake such work. I see no reason why the operator $Sd(qx)$ should not prove as fruitful in the development of q-Bessel and q-Hypergeometric functions as the ordinary integral has proved in analysis of the Bessel, Hypergeometric, Gamma and Double Gamma functions.

THE LAWS OF PHYSICS¹

By R. C. JUNNON M.A. M.Sc.

The existence of a general orderliness in Nature is for most scientists a fundamental postulate. We say with Kant that the idea of cause and effect is one of the given categories without which knowledge is impossible. Yet there are not wanting now those who are prepared to deny this natural orderliness and it has become of great importance to examine the foundations metaphysical and experimental of those laws of physics whose pursuit is our highest goal.

Physical laws are the expression of inviolable relationships and these are found not from exact measurements alone—for every experiment is a separate event—but with the aid of *working hypotheses*. These facilitate the deduction of the laws from the measurements. They are at once useful and dangerous; they are the product of a well trained and active imagination not of logical processes. The formation of a working hypothesis often involves mental reference to some parallel phenomena in another field and herein lies its danger. For there may enter into the hypothesis some idea which is essentially alien to the field where lies the experimental material awaiting coordination. The ideas of light and heat as forms of matter were faulty hypotheses on this account. Electricity only escaped being called a substance because it was of two kinds positive and negative; the ether did not escape. This tendency to regard any unchanging magnitude as a substance has often been a hindering influence and it may be noted that the most recent developments those associated with Heisenberg and with Schrödinger escape it by refusing substance even to electrons or protons.

A working hypothesis becomes a law in the scientific world when its ability to correlate the experimental material is generally recognized. This need not take a long time.

¹ Based on an address by Max Planck printed in *Die Naturwissenschaften* 13, p. 249, 1926.

for instance, we speak already of the law of relativity, though we still refer to the quantum hypothesis, which is in fact an older theory. But the process of purging the law from all foreign associations does take a long time. Its creator has invaded the new country across some happy bridge of imagination, bringing a parallel from more familiar territory, and he will be loath to examine the logical necessity of every step of his path with complete ruthlessness. His followers may accept the new and shining idea. So it was with Newton's great theory of force. The idea of force grew from analogy with muscular force, and seemed invaluable in its many applications (It is so still in the *teaching* of physics.) But it stood for no reality in the domains of gravitation, of magnetism or of electricity, and by withdrawing attention from the examination of the field where the "forces" occurred, it hindered more complete explanations. When it was seen that the less vivid idea of potential was a more fundamental one, immediate progress was made. Since our ideas are first created from perceptions, progress will involve our retaining conceptual images. But the laws themselves must be freed from these, although their logical consequences must be re-translated into terms of sense phenomena before they can be tested. 'The simplicity and generality of physical law only appears after the abstraction of every anthropomorphic element.'

The most troublesome element in physical law is *time*, probably because it is here that we can least easily free ourselves from direct perception. Before considering its place in modern theories of energy and relativity, we would notice that it is a factor dividing all physical laws into two great groups. Some laws are still valid if the time factor is reversed; this is true in the domain of electrodynamics and of mechanics, apart from friction. The others concern phenomena which come to an end in time, and these are irreversible, like the diffusion of one liquid into another, or the cooling of a hot body. The second class is the larger, and includes great and valuable

generalizations like the Second Law of Thermodynamics. It is now clear that laws of this kind are all approximate and are based upon statistical averages of enormous numbers of random changes. The theory of probability has had amazing success in revealing the inward meaning of the laws of this second class. It has achieved this success by assuming that the fundamental operations which are co-ordinated in the laws are governed by chance and by chance alone. Therefore we are obliged to ask whether the reversible laws are also founded upon purely random changes—changes so fine as to have escaped separate analysis and recognition up to the present. And because we must confess that no physical law has been proved to be *absolutely* true, it is possible that the answer is in the positive. Perhaps there is no fundamental orderliness in nature—that chance reigns not law. We shrink from this conclusion. Certainly its acceptance would have a baneful influence upon the prosecution of further research. Science cannot spare the postulate of strict causality although a few ultra-modern scientists would have it so. There is in the time factor which has revealed this dilemma some quality which philosophy has yet to unravel. And in the interests of sound progress science must not only believe in law but strive until every statistical law is reduced to prime-dynamical causes.

Relativity has set the crown on classical physics, in fusing the separate notions of space and time, mass and energy, gravitation and inertia into one whole. It has done this partly by purging the idea of time from one of its false assumptions that events which are simultaneous to one observer must necessarily be so to another observer. Its fruit is the unassailably symmetrical form which the laws of the conservation of energy and of impulse assume, as equivalent deductions from the principle of least action, the most comprehensive of all physical laws. But it fails, equally with all preceding theory to co-ordinate a number of simple experimental facts in all branches of physics—such as the values of specific heats at low temperatures, the

wave-lengths of perfect radiation the liberation of photo-electrons, to name only three

For these clear facts our only working hypothesis is the quantum hypothesis—that energy is atomic, like matter, in many of its manifestations. It has been employed with such success in so many different fields that we are almost forced to conclude that we have stumbled upon a new fundamental physical principle. Yet repeatedly it comes into direct logical contradiction of all previous physical laws. That a mechanical system should permanently admit only discrete values of energy seems hardly deducible from a theory of fields working as usual with differential equations. The method of De Broglie and Schrodinger has made some progress toward a solution—but it has dispensed with the localization of the mass particles and with strictly causal laws. The very possibility of a system of measurement which can clearly be brought into consonance with physical experience has been denied. It is difficult to imagine that some new and crucial experiments could throw light upon these conflicting theories, as experiments have often done before. We should rather hope that a deeper analysis of the principles involved in the formulation of the laws of physics may soon be obtained, and that from the present period of “Sturm und Drang” in physics there may again emerge a logical and all-inclusive unity.

ON THE INHERITANCE OF FOOD HABITS IN
THE HYBRIDS BETWEEN THE GEOMETRID
MOTHS *PÖCILOPSIS POMONARI* HB. AND
P. ISABELLEÆ HARRISON

By J. W. HESLOP HARRISON, D.Sc., F.R.S.E.

As an outcome of a recent and apparently successful attempt (Harrison, 1927) to transfer one of the phytophagous Hymenoptera, *Pontania salicis*, to a food-plant other than that to which it had been accustomed, interest was aroused as to the nature of the inheritance of such features as egg-laying instincts and food habits, and one naturally speculated as to whether it proceeded on Mendelian lines or not.

To decide this, no material seemed more suitable than that provided by the Lepidoptera, for, assuredly, the egg-laying instincts and food habits in that group are inherited. One has only to watch a Small Copper Butterfly (*Heodes phœas*), as it flits up and down some sunny bankside in search of its food-plant, deliberately shunning the various plants presented and choosing even the tiniest scrap of *Rumex acetosa* and *R. acetosella*, or to offer a newly hatched larva of the Brimstone Butterfly (*Gonepteryx rhamni*) a choice of mixed plants (including its own *Rhamnus*), to be convinced of this.

The two examples just cited are not taken at random, for it is very necessary to discriminate between the egg-laying instinct of the parent insect and the food habit of the larva. For instance, if males of *Pergesa elpenor* and females of *Celerio hippophaes* are enclosed in a cage containing *Epilobium* and *Hippophae rhamnoides*, the respective food-plants of these two hawk moths, pairings take place with facility, and eggs are obtained. All, however, are laid on *Hippophae rhamnoides*, since the inherited instincts of *Celerio hippophaes* females force them to select that plant for oviposition. In due course the eggs hatch,

but not a single larva will accept *Hippophae* as food; unless they are transferred to some species of *Epilobium*, the food plant of the male parent, they perish miserably (Denso, 1909). Thus we learn that the male insect plays its part in fixing the food habit; in other words, the matter is one of heredity.

However, not all species are suitable for the work projected. Clearly, if the research is to be satisfactory, two species must be secured, closely enough allied to provide fertile hybrids, but sharply separated in the matter of food plant. Such a pair I thought I had available in the two Geometrid moths *Ypsipetes ruberata* and *Y. trifasciata*, two species regarded by such systematists as Meyrick (1895) as one and the same, the former, nevertheless, attached in this area to sallow (*Salix aurita*) and the latter to alder (*Alnus rotundifolia*). Reciprocal pairings between these two species were easily obtained, and so were fertile eggs. None of the latter, however, hatched, and work with these insects had to be abandoned.

Fortunately enough, crossings carried out in the Geometrid sub-family *Bistoninae* for other purposes furnished all the data required. As will be seen in earlier papers (Harrison, 1916, 1917), the food plants of the species of this group vary with the genus and only rarely with the species, the members of the genus *Lycia* accepting as their larval food many deciduous trees and shrubs, and those appertaining to *Nyssia* favouring, similarly, such low-growing plants as *Achillea Millefolium* and *Lotus corniculatus*. In the genus *Pasiphilopsis*, *P. pomonaria* and *P. rachelae* partake of the same food plants as *Lycia*, whilst *P. lapponica*, not rejecting these plants, is to be found in addition on *Krica cinerea* and *Myrica Gale*; on the other hand, *P. isabellae* confines itself for food to the larch (*Larix decidua*).

Since *Lycia hirtaria* hybridizes with *Nyssia gracaria* and *N. zonaria*, it might be anticipated that the information sought would be obtainable from their various crosses. Such is not the case for the F₁ hybrids are uniformly

sterile. Notwithstanding this, the crossings between *N. grisearia* and *V. zonaria* females and *L. hirtaria* males supply a very useful fact and that corroborative of the evidence of the *Pergea Celerio* hybrid mentioned above, not a single larva issuing from these two matings will eat *Achillea*. They must be reared on hawthorn (*Crataegus oxyacantha*) or some other plant acceptable to *L. hirtaria*, again, without any possibility of doubt, the influence of the male parent is felt in settling the food habit. Luckily, no such check as F_1 sterility reveals itself in hybrids between *Paeциopsis pomonaria* and *P. isabellae*¹; although in the original experiments much loss was encountered amongst the emerging larvae, this was entirely obviated in later work the F_1 insects thus proving as fertile as the pure species.

II THE EXPERIMENTS

Reciprocal matings were made between *P. pomonaria* and *P. isabellae*, and the fertilized females allowed to lay their eggs in crushed paper, or beneath the imbricated scales of larch cones. As many more larvae hatched than could be managed when full grown, the surplus was employed to test predilections for the alternative food plants. To do this, the young larvae were enclosed in air-tight, glass topped tin boxes, some with hawthorn and others with larch.

Quite independently of the parentage of the hybrid, without a single exception, the former plant was accepted and the larch refused. Hence, had the cross-pairings taken place in nature, that between *isabellae* female and *pomonaria* male would have yielded no progeny, for the newly emerged larvae of that origin preferred death to eating larch, in spite of the fact that the female would have laid its eggs, under ordinary conditions, on that tree.

¹ Since *Paeциopsis isabellae* is confined to Europe, and its food plant larch is a postglacial immigrant into our continent, it is practically certain that *isabellae* is a very recent development from *P. pomonaria*.

These observations are not in themselves at variance with Mendelian expectation if one regards the hawthorn feeding habit as dominant. However the crucial tests as to Mendelian or non Mendelian inheritance do not lie in F_1 batches but are to be sought in the behaviour of back crosses and various F_2 combinations.

Of the possible back crosses only those between *isabellae* females on the one hand and males of the reciprocal F_1 hybrids on the other were brought about although these were repeated in succeeding seasons. In both crosses nearly every ovum yielded its larva and once more an abundance of larvae could be spared for food tests which were conducted precisely as with the I_1 insects. To my great astonishment instead of being confronted with a refusal of larch as before in every case in which it was offered I found it eagerly accepted whilst hawthorn was just as emphatically neglected.

In the original back cross between a *isabellae* female and a male of parentage *isabellae* female \times *pomonaria* male very few insects were bred although the percentage was substantially greater in later batches and in the reverse cross. This mortality in my earlier work (1917) I assigned to the selective elimination of zygotes physiologically nearer *P. pomonaria* when placed on a larch diet but the position can no longer be maintained in view of repeated failures to rear *P. isabellae* itself on larch derived from the same sources. Besides such an explanation takes no cognisance of the avidity with which the whole of the larvae devoured larch or of the circumstance that the deaths recorded were not preferential to any instar or instars but were spread over the entire period of larval life.

Nor were the conditions noted in the F_2 , F_3 , and F_4 lots and the various combinations thereof very different. Irrespective of the parentage of these more complex hybrids, or of the numbers of larvae hatching successfully in the different batches no effort of mine could induce the larvae to feed upon larch every larva persisted in its preference for a hawthorn diet like its I_1 relatives.

In addition to these crosses in which only *P. pomonaria* and *P. isabellae* participated matings were secured between *Nyssa zonaria* females and F_1 and I_2 males of the *isabellae* female \times *pomonaria* male crosses and also between I_1 females of the latter parentage and an F_1 male derived from a cross between *lapponaria* female and *pomonaria* male. Once again despite the disturbing factor introduced by a *zonaria* female reared on *Achillea Millefolium* and taken from a race accustomed to the same diet every larva in the first two cases had to be provided with hawthorn to the absolute exclusion of *Achillea* and *Larix*. Moreover the same procedure had also to be adopted with the batch obtained from the third and more complicated cross.

III DISCUSSION

As we have noted the broods reared fell into two categories in respect to food habit and as exact details as to the parentage of the individual batches have not been supplied these are incorporated in the following list in which the food habit is also indicated.

1 *Hybrids accepting only larch*

- (1) *Isabella* female $\times F_1$ (*isabellae* female \times *pomonaria* male) male
- (2) I_1 , (*isabellae* female \times *pomonaria* male) female \times *isabellae* male

2 *Hybrids accepting only hawthorn*

(a) Crosses involving *P. pomonaria* and *P. isabellae* only

- (1) F_1 *pomonaria* female \times *isabella* male
- (2) F_1 *isabella* female \times *pomonaria* male
- (3) F_2 *pomonaria* female \times *isabella* male
- (4) F_2 *isabella* female \times *pomonaria* male
- (5) F_3 *isabella* female \times *pomonaria* male
- (6) F_4 *isabella* female \times *pomonaria* male

- (7) F_1 (*isabellæ* female \times *pomonaria* male) female $\times F_1$ (*pomonaria* female \times *isabellæ* male) male
- (8) F_1 (*pomonaria* female \times *isabellæ* male) female $\times F_1$ (*isabellæ* female \times *pomonaria* male) male
- (9) I_1 (*isabellæ* female \times *pomonaria* male) female $\times \Gamma_1$ (*isabellæ* female \times *pomonaria* male) male
- (10) [I_1 (*pomonaria* female \times *isabellæ* male) female $\times I_1$ (*isabellæ* female \times *pomonaria* male) male] female \times [F_1 (*pomonaria* female \times *isabellæ* male) female $\times I_1$ (*isabellæ* female \times *pomonaria* male) male] male

(b) Crosses involving these and other species

- (1) *maria* female $\times I_1$ (*isabellæ* female \times *pomonaria* male) male
- (2) *lonaria* female $\times I_1$ (*isabellæ* female \times *pomonaria* male) male
- (3) I_1 (*isabellæ* female \times *pomonaria* male) female $\times \Gamma_1$ (*lafponaria* female \times *pomonaria* male) male

So clearly are *isabella* and *pomonaria* differentiated in respect to food plant, that one naturally expects the inheritance of this character to proceed on a Mendelian basis. Indoubtedly nothing occurs in the Γ_1 generation to upset this opinion if one grants that the hawthorn feeding habit is dominant.

Very different however is the evidence provided by the back crosses. Here had segregation taken place in F_1 , gametogenesis in respect to the character studied, two classes of zygotes, occurring in equal numbers should have been represented. These as we have already perceived do not put in an appearance, since every larva is a larch feeder. Except that in their cases the broods uniformly feed on hawthorn, a similar lack of segregation is displayed by the F_1 and other more complex crosses.

Hence, any Mendelian elucidation of the situation on a single factor basis fails. Furthermore the position is not

altered by any assumption of multiple factors determining the habit in question. Even then the segregation of these in F_1 gametogenesis ought to have been emphasized in the zygotes of the back-crosses by some larvae at least taking to a hawthorn diet, and in the F_2 and other lots by some feeding on larch.

Segregation, therefore, seems to fail, and indeed, no explanation approaching in the remotest degree a Mendelian type appears to cover the facts, unless one admits gametic contamination so that the "genes" emerge from hybrid gametogenesis in an average or approximately neutral condition. To be exact, I should seek to account for the facts, as far as food habit is concerned, on the basis of a permanent blend.

To such a view the Mendelian would be loth to subscribe, but still, with a slight adjustment stated below, it would afford an adequate explanation not only of the assumption of a larch diet in the back-crosses, but likewise of the acceptance of hawthorn by the other hybrids set out in the table.

The original bias of the reciprocal F_1 hybrids toward hawthorn I take to mark the comparatively recent divergence of *isabellæ* from *pomonaria*. In other words, it seems possible that some traces of ancestral habits, latent in *isabellæ* germ plasm, but stirred into activity by the abnormal conditions of the F_1 organisms, have reinforced the tendencies inherited from *pomonaria*.

Here I would leave the position for the consideration of other workers, merely interjecting the warning that all forms of purely maternal inheritance have been examined and cast aside because of the manifest influence of the male parent in so many F_1 hybrids.

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ON THE USE OF THE BLEACHING ACTION OF CHLORINE IN THE RAPID DETECTION OF FATTY OILS AND THE INVESTIGATION OF SOME OTHER SUBSTANCES AND STRUCTURES OF GREEN CELLS.

By KATHLEEN B BLACKBURN, D.Sc., and MIRION THOMAS, M.A.

I THE CHLORINATION TECHNIQUE AND ITS USE IN CONJUNCTION WITH OSMIC ACID IN THE DETECTION OF FATTY OILS.—We have found during the course of experiments on the fat metabolism of certain green cells, that it is sometimes difficult to gauge, even approximately, the oil content of these cells by direct treatment with osmic acid, and subsequent examination under the microscope. Particularly has this been the case, when, as for example in the young cells of actively growing filaments of *Rhizoclonium hieroglyphicum*, dense and compact chloroplasts have obscured cell structures and the colour effects of staining.

Excellent preparations, in which oil is retained and stained black, may be obtained in about twenty-four hours by fixing in Champy's Fluid. This method is, however, too slow for the preliminary work over a wide field, in which we are at present engaged, or for laboratory work by the student whose time is limited.

We have exploited the well-known bleaching action of chlorine on plant pigments to obtain rapidly preparations which, when suitably stained, show oil and other substances and structures more clearly than when the staining reagents alone are used. When a green cell is placed in contact with chlorine water it is decolorized with astonishing speed: this we have shown using algal filaments; whole leaves of mosses, and liverworts; and sections of the leaves of ferns, conifers, and flowering plants. We are considering the chemical significance of this bleaching action, but at present we need only say that alcoholic solutions of the

chloroplast pigments are also rapidly decolorized¹

It has long been known that halogens quickly kill plant cells. Our observations indicate that artefacts accompany death only to a limited extent and we support Zimmermann² in his recommendation of chlorine gas as a fixing agent for many algae such as *Cladophora* and *Zygnema*. Indeed we have within five minutes demonstrated the chromosomes at the metaphase in *Zygnema* by first fixing with chlorine water, and then staining with aniline blue. We have however noticed that the protoplasts in cells of *Rhipidium* generally show some contraction after chlorination. Further chlorine water added directly to living cells containing oil drops deforms these drops and, simultaneously an interesting speckled effect appears possibly as a result of the local formation of additive compounds between chlorine and the carbon chains with unsaturated linkages in the constituent fatty acids of the oil. If however the cells are first treated with osmic acid and then with chlorine water these deforming and speckling effects are not apparent and a mount so prepared shows even the very small oil drops as dark spheres against the bleached background.

We recommend the following method of procedure when it is desired to investigate the oil content of green cells:

Immerse the specimen to be examined in a drop of per cent osmic acid placed on a slide. Leave for at least a minute. Add chlorine water until the material is bleached—this may be judged with the aid of a hand lens for of course microscopes should not be exposed to the corroding action of the volatile halogens. Wash with water and examine under a coverslip using a high power of the microscope preferably an immersion lens.

On the accompanying plate an attempt is made to illustrate by means of photographs the value of this

¹ Bromine water also reacts readily with the chloroplast pigments but we do not consider it to be quite as useful as chlorine water for microchemical methods as it seems to combine to give brown products with many of the substances found in cells.

² Czapek Biochemie der Pflanzen

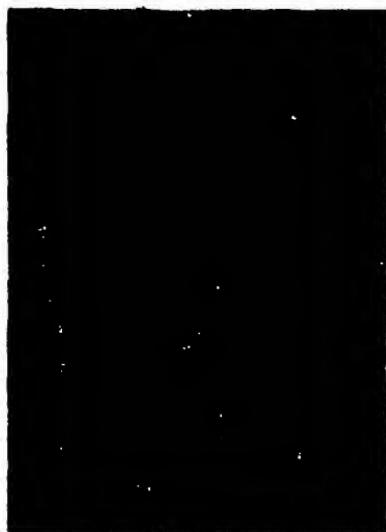
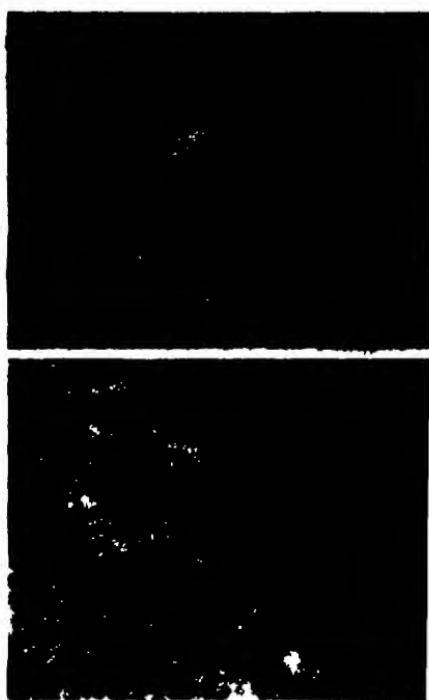
Zimmermann Botanical Microtechnique

technique in demonstrating oil in green cells. We have not coloured the illustrations, so they are not as convincing as were the preparations themselves. However a comparison of Figs 1 & 5 which are photographs of preparations treated with osmic acid only with Figs 2 & 6 which are photographs of the same preparations after subsequent chlorination certainly shows the clarifying effect of bleaching and that oil drops especially the small ones are then more easily seen. It is always possible to see those oil drops which are in proximity to the near surface of cells under microscopic examination but after chlorination oil drops other than these become visible. In high power microphotography the depth of focus is so limited that we cannot on the plate illustrate this advantage to the full.

Using this technique we have obtained good results with cells of the green algae [e.g. species of *Rhizoclonium* (See Figs 1 and 2) *Laucheria* (*Edogonium*, *Spirogyra*, *Zygnema*, *Ulothrix* and *Inbonema*) with whole leaves of mosses and liverworts [e.g. *Plagiochila* (Figs 3 and 4)] and with sections of the leaves of the higher plants [e.g., *Pteris*, *Taxus* (Figs 5 and 6), *Ilex* and *Imula*]. In no case do we claim that we are reporting for the first time the occurrence of oil in the green cells of these plants. We do claim however that our technique is an improvement on the usual method of direct staining with osmic acid and because of this we are using it in investigating the conditions which govern the formation of fatty oils in green cells.

2 CHLORINATION IN RELATION TO THE TANNINS IN CELLS

Osmic acid is reduced by tannins giving a black product which is possibly mainly composed of hydrated osmium dioxide.¹ Hence the addition of this reagent to cells containing tannins in solution in their vacuoles, such as those of *Spirogyra* and the mesophyll of some of the higher plants, leads to the production of a dark colour which so masks all



other effects, that it is nearly impossible to make critical observations. This product is oxidized with decolorisation by chlorine water, and so the value of our technique is enhanced. We must, however, mention that the chlorination of cells containing tannins, leads to the appearance of a pale yellow-brown colour, and this is no doubt due to the oxidation of the tannins by the chlorine water—a reaction which may be readily shown in the test-tube.

It is well known that highly refractive globular tannin vesicles are found in the cells of *Zygnema*, and that these vesicles are stained black by osmic acid hence direct tests with this reagent may cause them to be confused with any oil drops which may be present. On the addition of chlorine water however, the vesicles are decolorized and disorganized, leaving the oil unchanged as yellow-brown spheres. The vesicles are also disorganized by bromine water and by iodine water, and we intend to investigate this phenomenon later.

3 THE RECOGNITION AND LOCALIZATION OF STARCH AFTER CHLORINATION—It is possible to show the presence of, and to localize even small quantities of starch in cells previously bleached with chlorine water. Care must be taken to wash out the excess of chlorine with water before testing with the iodine reagents, since the blue "starch-iodide" colour is discharged by chlorine. Chloral hydrate-iodine (Schimper's solution) very quickly shows up all the starch grains, but it distorts them, and because it also profoundly disintegrates cell structures, it is not always suitable for localizing the grains with exactitude. Strong solutions of iodine in potassium iodide stain the bleached chloroplasts a deep brown, thus making it difficult to see small starch grains.

By using saturated aqueous iodine—a reagent quickly prepared by heating iodine crystals with water—we have obtained neat preparations showing very small starch grains within the bleached chloroplasts of *Spirogyra*, *Rhizoclonium*, *Edoyonium*, and *Funaria*. This use of

aqueous iodine after chlorination is a variation of older methods and may sometimes prove useful although in practice we have not always found it completely satisfactory

4 THE INVESTIGATION OF CELL STRUCTURES AFTER CHLORINATION—We have already indicated that chlorine water fixes cell structures satisfactorily. Hence it is a useful reagent in rapid investigations of the characters of these structures in green cells. For example after chlorination of the cells of the green algae the number of nuclei, the shapes of the chloroplasts, the position and number of the pyrenoids and their relation to starch may be readily studied by staining with such dyes as maline blue or aceto carmine.

DESCRIPTION OF THE PLATE

Microphotographs taken on Panchromatic plates using a 2mm Leitz apochromatic objective. These show the appearance of tissues first after adding 2 per cent osmic acid and second after subsequent bleaching of the chloroplast pigments with chlorine water. As nearly as possible the same focus was used in making each pair of photographs.

Figs 1 and 2—Part of a filament of *Rhizoclonium hieroglyphicum* ($\times 700$) Fig 1 before chlorination Fig 2 the same cells after chlorination

Figs 3 and 4—Mesophyll cells from a section of a leaf of *Ilex baccata* ($\times 470$) The palisade cells are on the right and the spongy cells are on the left of the photographs Fig 3 before chlorination Fig 4 the same preparation after chlorination

Figs 5 and 6—Cells from a whole leaf of *Plagiochila asplenoides* ($\times 600$) Fig 5 before chlorination Fig 6 the same cells after chlorination

A comparison between the pairs of photographs described above, particularly between Figs 1 and 2 and between Figs 5 and 6, will show that the bleaching of chloroplast pigments so clears the background that oil drops especially the small ones are more readily seen.

Reference is made to the plate on page 204 of the text.

A PETROLOGICAL INVESTIGATION OF THE COAL MEASURES SEDIMENTS OF DURHAM

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(Prague)

Owing to the two-fold lack of well established seam correlations and recognizable fossil bands no well defined horizon exists in the coal measures strata of the Durham coal field.

That it is possible to correlate rocks by means of their mineral content and as a corollary to this to recognize definite horizons marked by a definite assemblage of minerals has been proved in the oil fields of southern U.S.A.¹ H. B. Milner has also shown the value of the mineral assemblages of rocks in proving contemporaneity².

The present research was undertaken with the primary aim of discovering whether or not there existed in the coal measures strata of Durham either any band of rocks with a mineral assemblage sufficiently different from the rocks above and below to be distinctive and recognizable or a change in the mineral assemblage at some horizon in the strata sufficiently great to be distinctive and recognizable.

One result of the work has been to show that during the period of time represented by the strata examined (*viz.*, from below the Marshall Green Seam to the highest known coal measure beds in Durham) the same parent rocks were being laid under contribution in order to provide the coal measure sediments. Hence there cannot be any well marked change in the mineral assemblage in the strata at any point.

During the deposition of the sediments it would be possible for localized conditions of transportation and deposition to cause concentration of certain minerals in particular places. In these places the relative proportions of the minerals would be very different from that generally found throughout the strata. Such abnormal concentrations have been observed at certain horizons in two places.

THE TREATMENT OF THE SAMPLES

Figure 1 gives a diagrammatic view of the coal-measures strata and shows the relation of the samples examined to the coal seams. It will be noted that the strata have been sampled from just below the highest seam in the coal-field, i.e., the Closing Hill Seam, to some 300 feet below the Brockwell Seam, and well below the lowest workable seam in the coal-field, i.e., the Marshall Green Seam.

Each specimen was crushed carefully (not ground) in order to separate all grains, leaving no composite particles. Ten gramme samples were used, and by means of the settling method, the clay and fine-silt grades (i.e., all material below 0.05 mm diameter) were removed.

Some time was spent in determining experimentally the depth of water necessary, and the time required to allow the sediment to settle for various grade separations. By actual trial and measuring the grains under the microscope, the following Table was compiled.

Grade	Height	Time
0.01 mm	4.5 cm	5 mins
0.05 "	10.0 ,	55.5 secs
0.1 "	14.0 ,	21.0 ,
0.2 "	20.0 ,	10.0 ,
0.25	25.0 "	10.0 ,
0.3 "	32.0 ,	10.0 ,
0.4 "	47.0 ,	10.0 ,

Having separated the clay and fine-silt grades, the dried residue was separated by means of Bromoform (specific gravity 2.86) into a "heavy" and "light" crop. The heavy crop was weighed and the percentage of heavy minerals recorded.

In order to make an accurate comparison of the relative amounts of the various minerals occurring in the different specimens, the following procedure was adopted. After

FIG I

Showing the Position of the Samples Examined in Relation to the Principal Coal Seams of the Durham Coalfield, and also the Relative Proportions of the Various Heavy Minerals at each Horizon

STRATA and SEAM	SAMPLE NO.	% HEAVY MINERAL	MINERALS												PRESENT								
			ZIRCON	TITANITE	LEUCITE	ANATASE	PALADONITE	COROTITE	SPINEL	PEROVSKITE	APATITE	MAGNETITE	SQUENITE	PIRIMESITE	SPINETITE	CHALCOFERRITE	EPIDOTE	QUARTZITE	ALUMINITE	SPHALERITE	SLIMMITE	ANATASITE	SPINELITE
FOUR INCHES THICKNESS																							
THREE QUARTERS SEAM	E, LOW	3 1 1 3 6 1 6 1 1													✓ ✓ 1								
THREE QUARTERS AND FOURTH SEAM	E, 12	2 12 5 5 3 4 6 1												1 9	✓ ✓ 1								
FIVE QUARTERS SEAM																							
THREE QUARTERS SEAM	GP, 0.65	6 2 5 4 6 1 7 3 3													1								
SEVEN EIGHTH SEAM	D, 1.45	6 6 2 7 —											4 6 7	✓									
	D, 2.48	5 4 1 7 3 1											2 9 4	✓	1								
	D, 7.83	5 3 3 3 — 7 8 1 2													2								
	D, 3.8	6 4 5 3 — 9 1 2													1 2								
	D, 8.04	6 8 5 3 — 7 4												✓ ✓	✓								
FOUR EIGHTH SEAM	D, HIGH	4 3 2 1 — 9 9 1																					
	D, 8.38	4 2 2 2 5 9 2													1	1							
THREE QUARTERS SEAM	D, 0.46	6 4 3 1 5 3 4											6 1	✓	6	✓ ✓	6	✓					
	D, 2.0	4 2 2 4 7 1											9 1	1			9	1					
	D, 6.75	4 2 3 3 7 1											9										
	D, 7.15	6 3 3 1 4 2 4											5		1								
	D, 6.58	2 1 1 4 1 1 1											9										
	D, 8.7	4 3 3 1 6 2 4											4										
	D, 1.56	5 4 3 6 5 1 2											✓		1 2		✓ ✓						

Fig. I (continued).

	SAMPLE	% HEAVY MIN.	IRON	MAGNETITE	HAEMATITE	TAUFEKITE	LEPIDOLITE	QUARTZ	ANATASITE	STIBNITE	ANTIMONY	CHALCOGENIDE	CHALCOBISMITE	CHALCOGRAPHITE	CHALCOQUARTZ	CHALCOBISMITE	CHALCOGRAPHITE	CHALCOQUARTZ	
MANSON SEAM	D _a 139	4	3	2	2					9									
	D _a 158	7	3	3	4	6	2	7	2	2	9		✓	1					
	D _a 123 ^b	6	3	5	7	8	2	1	3	2		✓	?						
	D _a 336	6	4	5	5	7	0	9		3			?						
	A _a 2110	2	1	1	1	6	7	9		4									
ON MAIN SEAM	A _a 3145	7	1	1		6	7	9	2	5									
HUTTON SEAM	B _a 042	8	2	3	2	0	7		4				5						
HARVEY SEAM	C _a 301	7	1	4	1	4	?	8	3	1	8		✓						
	C _a 1469	8	2	5		2	2	4	1	6	8		✓						
BUSTY SEAM																			
BRICKHILL SEAM	F _a 246	4	2	2	1	0	4	2	✓	9		✓	✓	2					
	B _a 08	7	2	3	2	1		1	3	7	7		1	1	✓				
VICTORIA SEAM	F _a 099	7	1	4		1	✓	7	3	9			1						
	B _a 142	3	1		2		0	9	2	6		✓	✓	2					
	ZY 146	7	4	3	4	5	0	6	4	1			✓		✓				
	F _a 333	3	1	2	4	1	✓	5	3	8	5		2						
MAIN ON GREEN SEAM	F _a 117	8	1	4	1	4	✓	8	3	2	9		✓	✓	2				
	F _a 098	2	3	2	1	4	2	3		1	9	2							
	F _a 081	7	1	2	1	1	✓	8	3	1	6	2	✓	2					
300 ft from BRICKHILL SEAM	F _a 105	6	1	3	1	✓	9	2	1	8			1		✓				

NOTE ✓ SHOWS A MINERAL IS JUST PRESENT

* SHOWS A MINERAL IS PRESENT BUT RELATIVE AMOUNT IS NOT ASCERTAINABLE FROM NOTES

having determined all minerals in a preparation, some twelve to twenty fields were examined microscopically, and the number of the various minerals in each field noted. An average relative occurrence for each mineral could then be calculated for the specimen. This gave a basis from which Tables such as Figure 1 could be constructed. The numbers shown in Figure 1 indicate the relative amount of the minerals.

In order to show the persistence of varieties of minerals vertically in the strata, the method shown in Table 1 was adopted.

TECHNIQUE.

In order to obtain the percentage of heavy minerals in each specimen, it was necessary to take a weighed quantity of the original rock. As it was necessary to know what minerals occurred in each rock, it became important to determine the exact size of specimen to take. Obviously the larger the sample examined the more representative was it likely to be with regard to mineral content.

It was found that 10 grammes samples were, from the point of view of economy of Bromoform, and speed of separation, the best to use. Not being satisfied that 10 grammes samples were representative of the mineral content of the rocks at the horizons sampled, six specimens were selected which had previously been examined by means of 10 grammes samples. In each of these six specimens, a kilogramme of rock was crushed, and panned to some 40 grammes. This heavy residue was then separated with Bromoform and the heavy mineral crop examined.

In no case was any heavy mineral found which was not found in the 10 grammes sample. Table 1 shows for the four principal heavy minerals (zircon, garnet, rutile, tourmaline) the varieties found. It will be noted that a kilogramme yields more varieties of the minerals recorded than does the 10 grammes sample.

Because the same parent rocks have contributed similar minerals and varieties of minerals throughout the period

TABLE I

Showing the Varieties of Zircon, Garnet, Rutile and Tourmaline,
in the Coal Measures of Durham.

	SAMPLES									
MINERAL VARIETY	E	E	F	G	H	I	J	K	L	M
ZIRCON	1	2	3	4	5	6	7	8	9	10
GARNET	1	2	3	4	5	6	7	8	9	10
RUTILE	1	2	3	4	5	6	7	8	9	10
A	1	2	3	4	5	6	7	8	9	10
TOURMALINE	1	2	3	4	5	6	7	8	9	10
b	1	2	3	4	5	6	7	8	9	10
c	1	2	3	4	5	6	7	8	9	10

Legend:
 █ SHOWS PRESENCE OF MINERAL IN 10 GRAPHIC SAMPLE
 ◻ SHOWS PRESENCE OF MINERAL IN PANNES BUT NOT IN 10 GRAPHIC SAMPLE
 ? SHOWS PRESENCE OF MINERAL VARIETY, BUT CHARACTERISTICS NOT DEFINITELY ASCEMMENDED FROM PANNES

represented by the rocks under investigation nothing has been lost by not examining panned samples of each specimen as well as the 10 grammes samples. In cases where rocks are under investigation representing a period of time during which at certain intervals fresh parent rocks of different type were laid under contribution it would be necessary to trace all minerals and also all varieties of these minerals. Hence both 10 grammes and panned kilogramme samples should be examined in investigations similar to the present one.

MINERALS OF THE HEAVY ROCK

Figure 1 shows for each specimen examined

- (a) The percentage of heavy minerals
- (b) The various heavy minerals and their relative amounts

The distribution of the varieties of the four principal heavy minerals are shown in Table 1.

It will be noted from Figure 1 that the percentage of heavy minerals in individual specimens ranges up to 31.48 per cent. The average percentage of heavy minerals for the strata is 5.45 per cent. Those rocks in which the percentage of heavy minerals is greater than 5.45 have either large amounts of biotite decomposition products or of siderite or both often with pyrite, in addition. Those rocks without these secondary minerals in predominating amount have a very small percentage of heavy minerals.

Since the bulk of the evidence afforded by the minerals of a rock regarding the parent rocks is to be obtained from the alloigenic minerals and since these minerals are the only ones upon which evidence of mineral horizons can be based the alloigenic minerals of the coal measures strata have been examined in detail. The four principal heavy minerals found (zircon, garnet, rutile and tourmaline) will be described in detail in order to illustrate how deductions regarding the origin of the coal measures sediments were arrived at.

THE FOUR PRINCIPAL ALLOGENIC HEAVY MINERALS.

Zircon. (See Figure 2.)

The following seven varieties of zircon are found in the coal-measures of Durham.

- (a) Colourless, clear, usually pyramidal prisms; rarely basal sections; unworn or very slightly worn; facets always present; inclusions almost invariably present.
- (b) Colourless, clear, more or less rounded; no facets.
- (c) Grey, clouded, dull; very much worn; no undamaged facets; often zoned.
- (d) Grey and pocked; dull, often blistered; very worn and rounded; often potato-shaped and bent.
- (e) Pinkish-grey; clouded; often zoned; fairly well rounded; no facets, often the remnants of double pyramidal prisms shown.
- (f) Yellowish-brown, usually with pyramidal prisms; occasionally very worn and rounded; usually no facets; birefringence colours indistinct.
- (g) Pale green; well worn and rounded grains; no facets; birefringence colours indistinct.

Garnet. (See Figure 4)

The following five types of garnet have been noted:

- (a) Pink; well rounded outline; somewhat pocked surface; cleavage present, but not incised.
- (b) Colourless; ragged and toothed outline and rough surface; distinctly cleaved.
- (c) Pink; otherwise similar to variety (b)
- (d) Colourless; incised cleavage not intensely developed, hence the mineral has an irregular but not a ragged toothed outline. The step-like surface is a striking feature. Where grains have broken along a plane of cleavage, "flakes" of this variety yield colourless uncleaved grains with bright smooth surface and somewhat regular outline.
- (e) Pink, otherwise similar to variety (d).

FIG(2)

ZIRCON



FIG(3)

SAPHIRE



BLUE AND BLUE-GREY



FIG(4)

GARNET



Rutile (See Figure 5)

The following six varieties of rutile were differentiated from one another by means of colour, and each again subdivided according to habit

(a) *Dark Brown to Black*

- 1 Euhedral prisms with facets well preserved, usually with broken irregular terminations, occasionally with pyramidal facets well preserved
- 2 Broken irregular grains showing no facets, prismatic form sometimes distinguishable, often ribbed parallel to the prism edge
- 3 Long, slender, clear needles

(b) *Amber*

- 1 Prismatic grains with facets preserved, with or without terminal facets or pyramids Slightly pleochroic
- 2 Broken, worn stumps similar to variety 1
- 3 Irregular, broken grains
- 4 Euhedral grains, with six, seven or eight sides

(c) *Greenish-Brown*

- 1 Prisms with facets preserved, terminal facets present
- 2 Broken grains similar to variety 1
- 3 Irregular broken grains

(d) *Purplish-Brown*

Slender prisms with facets Terminal facets occasionally preserved

(e) *Foxy-Red* (pleochroic)

- 1 Double pyramidal prisms, also prisms with broken terminations Facets well preserved
- 2 Tiny grains, apparently the worn stumps of prismatic grains
- 3 Large and small grains of irregular outline—evidently broken from grains originally large.
- 4 Long slender needles

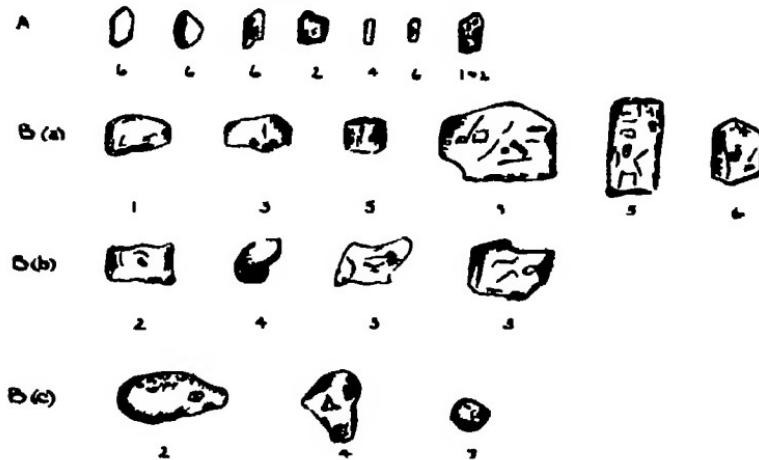
FIG(3)

RUTILE



FIG(6)

TOURMALINE



(f) *Yellowish Brown and Golden*

- 1 Prisms with terminal facets or broken irregular terminations
- 2 Small grains evidently the worn stumps of variety 1
- 3 Needles long and slender With or without terminal facets Prism faces well preserved

Tourmaline (See Figure 6)

Two principal varieties of tourmaline are distinguishable

A tiny euhedral prisms usually with pyramidal terminations often slightly rounded and generally partially decolorized

B Large grains

In variety A the colours are mainly shades of brown A few bluish green and blue grains were noted In Table 1 the numbers 1 to 10 correspond to the various colours noted in variety A

Variety B is divisible into three classes

- (a) Prismatic with one or both pyramidal terminations or irregular or broken terminations Generally somewhat rounded facets rarely perfect Inclusions are usually present Numbers 1 to 13 in Table 1 correspond to the various colours these are mainly shades of brown A few grains with greenish tints were found
- (b) Usually very angular practically unworn grains apparently broken portions of grains similar to variety B(a)
- (c) Worn rounded grains showing no facets or crystal form The colours are mainly shades of brown and green

THE HISTORY AND PARENT ROCKS OF THE ZIRCONS

Varieties (a) and (b) are both from the same type of rock, namely igneous or metamorphic rocks which on denudation yielded clear colourless zircons usually containing inclusions

Variety (b) resulted from the denuded material having

undergone attrition before being finally deposited. This is borne out by the fact that (b) is usually the predominant variety in the finer grained sediments. When variety (a) occurs in the finer grained rocks the crystals are usually long and needle shaped with quite unworn facets showing clearly that they had been carried into their present position as inclusions in mica which abounds in these finer grained rocks. Such needle shaped prisms are absent in the coarser sediments where mica is usually scarce and the zircon are relatively large sized.

The frosted surface and consequent clouded appearance of variety (c) has been caused by prolonged attrition. The extreme rounding and absence of facets lends further support to this conclusion. The evidence of extreme attrition shows that this variety has had quite a different history from the grains of varieties (a) and (b).

In some of the finer grained rocks variety (c) forms the whole of the zircon crop except for a few tiny colourless prisms of variety (b) or of variety (a). Variety (c) is by far the predominating member of the zircon family in the coarser grained rocks. It would seem that the parent rocks of (c) supplied a large portion of the material of the coal measure sediments.

P Armstrong concludes that

- (a) Blistering of zircons may take place in igneous rocks due to resorption
- (b) Blistered rounded sausage shaped grains may occur both in ortho and para gneiss due to local melting and coating of the grains
- (c) The shape of zircons cannot be used as a criterion of derivation from ortho or para gneiss

Undoubtedly zircons of variety (d) are from a different ultimate source and have had a different history from varieties (a), (b) and (c).

Zircons of variety (e) are identical with the type that Dr Mackie has named Purple Zircon. He has shown these to exist in formations ranging in age from Lewisian Gneiss to present day deposits.⁴ Further, he has shown

that the Lewisian Gneiss is the ultimate source of purple zircons of later formations.

The presence of purple zircons is no proof of direct derivation from Lewisian Gneiss rocks. They may be present owing to denudation of strata containing purple zircons and of intermediate age between Lewisian Gneiss and coal measures.

The extremely worn appearance of the grains of this variety and its small amount in the coal measures compared with its amount in strata known to be derived directly from the Lewisian Gneiss lends weight to this conclusion.

The parent rocks of variety (a) are undoubtedly either Acid or Intermediate igneous rocks or metamorphic rocks situated at a relatively short distance from the coal measure area of deposition.

Variety (b) is a worn facies of a variety similar to (a) and may have resulted from the denudation of igneous or metamorphic rocks situated at a relatively short distance from the coal measure area of deposition. On the other hand this variety may have resulted from the denudation of sedimentary rocks containing zircons similar to those of variety (a).

Sedimentary rocks have most probably contributed variety (c). It seems impossible that such greatly worn grains could result from the denudation of igneous or metamorphic rocks and be deposited in such a state of extreme attrition. They have undoubtedly passed through at least one intermediate sedimentary rock stage.

Judging from its worn appearance variety (d) has come either from an igneous or a metamorphic rock by way of an intermediate sedimentary rock.

As stated above variety (e) has most probably come to the coal measures from the Lewisian Gneiss via an intermediate sedimentary series.

Zircons similar to variety (f) are reported in granites and gneisses. The extremely worn appearance of the group suggests derivation from some intermediate sedimentary series.

The well worn grains constituting variety (g) also suggest derivation from some intermediate sedimentary rock.

THE HISTORY AND PARENT ROCKS OF THE COAL MEASURES GARNETS

The five varieties of garnet are distinct from one another, but the significance of the differences is not readily apparent.

Somewhat rounded pocked garnets are reported by many investigators and such garnet forms are said to be due to solution. Possibly this may be the explanation of the pocking of variety (a). If this is the case the solution must have taken place before the garnets reached the coal measure area of deposition, because other garnets, quite unaffected, occur along with variety (a) in the same rock specimen.

Varieties (b) and (c) differ only in colour varieties (d) and (e) also differ only in colour. It was noted that the (b c) group was always in very small grains while the (d e) grains were very often much larger than the average grain size of the associated minerals of the containing rock specimen. It would appear that the (b c) group has been subject to greater attrition than the (d e) group. This has resulted in the intense cleavage, and owing to the innate brittleness of the mineral, the extreme irregularity of outline and surface. The smaller size of the (b c) group is no doubt a result of extreme attrition. The (d e) group has suffered less attrition, therefore the grains are larger, less cleaved and less intensely broken and ragged than the (b c) group. It seems probable that the (b c) group has come to the coal measures from an intermediate sedimentary rock series.

THE HISTORY AND PARENT ROCKS OF THE COAL MEASURES RUTILES

The six varieties of rutile (a) to (f), are distinctive owing to colour differences. Minor sub-divisions of each are based upon differences of habit.

Variety (a) especially (a)2 is very persistent. Other varieties occur very spasmodically indeed rutile appeared to give grounds for hope that its varieties of colour and habit might enable it to be used as a zonal mineral until it was realized that petrologists are not yet decided as to which of its forms are authigenic and which allogenic.

Variety (b)4 causes specimen B 1 to have a very distinctive heavy mineral crop. Until it is known definitely that variety (b)4 is allogenic it is useless to attempt to utilize it for any zoning purposes.

The (a)2 variety of rutile is predominant in amount, and is undoubtedly allogenic in the coal measures. Its worn broken appearance indicates severe attrition either via a former sedimentary series or because of derivation from rocks (sedimentary igneous or metamorphic) situated far from the coal measure area of deposition.

Since variety (a)3 is quite undamaged by crushing during the preparation of the samples it is probable that the broken ends and slight damage to facets shown in variety (a)1 is due to attrition during transport from the parent rock to the coal measures.

Variety (a)3 judging from its perfect form and unworn facets, may be authigenic.

What has been said of variety (a) is equally applicable to varieties (b), (c), (e) and (f).

Variety (b)4 lends distinction to the heavy mineral crop in which it occurs. Its history is undoubtedly very different from that of (a)2 for example. The excellent state of preservation of form and facet gives strong support to the conclusion that the mineral has been formed *in situ*.

THE HISTORY AND PARENT ROCKS OF THE TOURMALINES

The tiny tourmaline grains of variety A are in the main pale coloured, and have apparently been bleached. The large grains of variety B do not show signs of bleaching to nearly such a great extent.

Variety A occurs in much less amount than B, while

B(a) and B(b) are most persistent in occurrence and largest in amount. Variety B(c) is very distinctive owing to its roundness of outline and intensity of colour.

Blue tourmalines are very rare and few in number, brown tints are by far the most prevalent, while pinkish and reddish straw tints are striking and frequent in occurrence.

While varieties A, B(a) and B(b) may not have been derived from sedimentary rocks the extremely worn appearance of B(c) suggests derivation from sedimentary rocks.

THE REMAINING ALLOGENIC MINERALS

In addition to zircon, garnet, rutile and tourmaline, the coal-measure sediments carry the following allogenic heavy minerals:

- Apatite
- Magnetite
- Chlorite
- Epidote
- Ilmenite
- Sphene
- Sapphire

These minerals have been examined and deductions made regarding their history and parent rocks, as was done in the case of the four principal heavy minerals.

Sapphire (see Figure 3) is a very distinctive mineral, but occurs at too many horizons to be of any value as a zonal mineral.

The minerals of the light crop are quartz, felspar and mica. Chert was present in nearly every specimen examined. Quartz is always predominating in amount, felspar and mica are variable in their relative amount.

The quartzes are of two types angular grains with facets frequently preserved, also subangular grains. The former seem to have had a different history from the latter. They appear to have undergone much less attrition.

Of the felspars, a few fresh orthoclases and microclines are occasionally seen. Small angular chips of plagioclase felspar showing albite twinning are usually fresher than the larger plagioclase grains. Oligoclase, and occasionally

grains of labradorite, have been noted. The bulk of the felspar, however, is so highly altered that determination of the type of felspar is impossible.

The fresh orthoclase is strong proof of acid igneous rocks having contributed material to the coal-measures sediments. Most probably some of the fresh microcline and some at least of the plagioclases have been derived from the same source.

The highly altered microcline suggests derivation from an intermediate sedimentary series.

Muscovite, with and without inclusions is invariably present in the finer sediments. In the coarser rocks the muscovite usually contains inclusions.

Biotite is occasionally absent. It occurs in various states of decomposition and decolorization.

THE PARENT ROCKS OF THE COAL-MEASURE SEDIMENTS

From the evidence afforded by the allogenic minerals, of which the foregoing is a brief review the following list is drawn up (*See Table on next page*)

From this list the following deductions are made:

1 In order to account for the presence of apatite, orthoclase felspar in fresh condition, and quartzes with facets preserved, it is necessary to postulate acid or intermediate igneous rocks amongst the principal parent rocks of the coal-measures sediments of Durham.

Such parent rocks would be able to supply zircons of varieties (a) and (b), possibly some of the rutiles, tourmalines of varieties A, B(a) and B(b), magnetite, chlorite, epidote, ilmenite and sphene.

The evidence deduced from the appearance of the apatite, zircon and quartzes, supposedly derived from these parent rocks, points to such rocks having been situated at such a distance from the area of deposition as to prevent any great attrition of the grains.

2 Sedimentary rocks must have contributed material to the coal-measures. This is demonstrated by

Mineral	Possible Type of Parent Rock						
	Acid Ig	Int Ig	Bas Ig	Gne ss	S hist	Met Aur	Sedi ment
Zircon	V r ety a						
	b	*			†		
	c						
	d						
	e						*
	f			•			
Garnet	a						
	c	*					*
Tourma line	a	*			†		
	•						
	b1					*	
	b2						*
	b3				*		
Apatite							
Magnetite	*					*	
F e idote	*						
Ilmenite				*			
Sphene		*					
Quartz	*						
Felspar	*						*

N B — * indicates Possible Parent

various of varieties (c) to (j) by some of the felspars (e.g. decayed microcline) and the very worn quartzes. Such parent rocks would also account for the garnets and tourmalines (varieties (a)1 (b)1 (c)1 (f)1) also tourmaline of variety (c) and possibly of variety A and perhaps some of the magnetites chlorites and ilmenites.

The absence of the Stress Minerals in any representative fashion as a group points to the fact that schists and gneisses have not directly contributed to the coal measures sediments.

It would seem therefore that a pre coal measure sedimentary series plus acid or intermediate igneous rocks (or both) were the chief sources of supply of the coal measures sediments.

THE LOCATION OF THE PARENT ROCKS OF THE COAL MEASURES

Judging from their age and geographical situation the igneous rocks of the following areas suggest themselves as possible sources of the igneous rock material of the coal measures.

- 1 Lake District
- 2 Southern Uplands
- 3 Cheviot Area

The Table on following page shows at a glance the principal igneous rocks with their age and degree of acidity in these three areas.

In considering the parent rocks of the coal measures sediments it was concluded that they must have been principally

- 1 Sediments of pre coal measure age
- 2 Acid or intermediate igneous rocks (or both)

Judging from the above table it would seem that the igneous rocks of the Southern Uplands have not contributed directly to the coal measures of Durham. Whether the granites and associated igneous rocks of Galloway have contributed is not quite so easy to determine. Because of

Region	Age of Rocks	Principal Rock Types	Relative Acidity
Lake District	Borrowdale Volcanics (Ordovician)	Andesite & Basic Tuffs Tuffs & Breccias of Medium Acidity Pyroxene Andesites Augite Andesites Rhyolites	Intermediate
	Lower Old Red Sandstone	Muscovite Biotite Granite (Greisenised) Biotite Granite	Acid
Cheviot Area	Old Red Sandstone	Andesites Augite Granite Biotite Porphyrites Quartz Felsites	Intermediate Acid Intermediate Acid
Southern Uplands	Ordovician Old Red Sandstone Carboniferous	Diabase & Diabase Porphyrite Andesites & Basalts Andesites & Olivine Basalts Picrites	Basic ,
			Ultra Basic

the abundance of sphene in the Galloway rocks and its absence in the Millstone Grit of Yorkshire, Gilligan⁵ decides that the Galloway rocks have not contributed to the Millstone Grit. Only one grain of sphene has been found in the coal-measures, which points to the conclusion that the Galloway rocks did not contribute to these sediments.

Rastall and Wilcockson⁶ have shown that the igneous rocks of the Lake District contain, amongst others, the following minerals—pyrrhotite, anatase, andalusite, and brookite. These minerals have not been found in the coal-measures.

Pyrrhotite is an unstable mineral and therefore could easily disappear, but anatase and brookite are both stable minerals, while andalusite is moderately stable, therefore these last three minerals could be expected in the coal measures if the Lake District rocks had contributed. Since these minerals are absent in the coal measures sediments, it must be concluded that the Lake District igneous rocks did not contribute.

From the available evidence it would seem that the Cheviot rocks have been one of the principal sources of supply of the coal measures sediments. No published account of the accessory mineral content of the Cheviot igneous rocks exists, but from descriptions of thin sections⁷ the minerals of these rocks are similar to those of the coal-measures supposedly derived directly from igneous rock sources. Exception to this is found in augite, and in olivine, which are found in the Cheviot rocks. The former mineral is only moderately stable, the latter is an unstable mineral, hence it is possible that both have disappeared during the degradation of the igneous rocks and the transport of the resulting degradation products.

In addition to the igneous rocks of the Cheviot area, it is possible that the clastic sediments of the carboniferous limestone series, old red sandstone and silurian of the Border district, have all contributed to the coal-measures of Durham.

TABLE II

Showing cases in which the proportion of any mineral differs conspicuously from the normal value

SAMPLE	ZIRCON	TOURMALINE	RUTILE	GARNET	APATITE	ILMENITE	SAMPLE	ZIRCON	TOURMALINE	RUTILE	GARNET	APATITE	ILMENITE
B ₁							D ₁₄						
E ₃	5						D ₁₆						
G P		5					D ₁						
*D ₁	5		7				D ₁₈			5			
D ₂				7			A ₂	2					
D ₃							A ₁	1					
D ₄		5					B ₂	8					
D ₅		5					C ₃						
D ₆							*C ₁		8				
D ₇							F ₁			5			
D ₈							R ₁						
D ₉							F ₂						
D ₁₀							B ₅						
D ₁₁							ZY						
D ₁₂	2						F ₄						
D ₁₃							F ₆						
*D ₁₄	8		5	6	2		F ₉	2					
							F ₁₂						
							F ₁₄						
Average proportion in all Samples							5 2	2 4	2 7	2 4	1 4	—	

MINERAL HORIZONS IN THE COAL MEASURES

An examination of figure 1 shows that during the whole of the coal measure times under review the same minerals continued to be deposited in Durham

Table 1 brings out the fact that during this coal measure period the same varieties of each of the four principal alloigenic minerals were being deposited

The conclusion to be drawn is that the same parent rocks have contributed the same minerals to the coal measures of Durham throughout the whole period. For this reason no mineral horizon of the type hoped for has been found and it would seem apparent that none can be found

The existing differences in the heavy crops are mainly superficial and are due to

- (a) Difference in the grade size of the constituent minerals
- (b) Varying relative amounts of the constituent minerals especially of the authigenic minerals

The authigenic minerals must be ignored in any consideration of peculiarities of rocks at different horizons which are due to variable amounts of the minerals contained in the present case attention should be paid to silicon tourmaline rutile garnet apatite and ilmenite

In Table 2 is given the result of a statistical analysis of the relative proportions of the above named alloigenic minerals. This Table shows

- (a) The average relative amount of these minerals for the coal measures strata as a whole
- (b) The relative proportions of the minerals which in certain samples are so far in excess of or less than the average relative proportions as to be conspicuous

It will be seen from Table 2 that rocks at three horizons stand out in respect to the relative amounts of their alloigenic minerals viz J 1 D 14 and C 1. If it can be shown that rocks from the same horizons at other spots in the coal field show similar outstanding relative amounts of the same minerals these abnormalities of relative proportions would

serve as an identification of the horizons. Such abnormalities of relative proportions of constituent minerals are, however, probably of very limited areal extent.

Specimen D 1 is about 13 fathoms above a thin seam in the South Shields district, which is probably the equivalent of the Northumberland Stone Coal, or the Durham 5/4 Seam. D 14 is also from the South Shields area, and is from 3 fathoms above the Bensham Seam. Sample C 1 is from the strata immediately below the Harvey Seam at New Bancespeth Colliery, County Durham.

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ON THE WEATHERING OF CHEVIOT GRANITE UNDER THE PEAT

By S. J. I. MCKEEFF F.G.S.

In studying the process of weathering of rocks we are confronted with one great difficulty i.e. the precise determination of material removed in solution. The products of weathering are usually earthy and even when they are more or less coherent the difficulty of determining the pore space is very great. Without an accurate knowledge of the pore space (assuming that there are no secondary minerals deposited) the estimation of the loss for each oxide becomes purely conjectural. G. P. Merrill used to take the least soluble compound (Al_2O_3 or Fe_2O_3) as an invariant (standart oxide) and then to recalculate the analysis of the weathered rock in such a way that the standart oxide had the same numerical value as that in the fresh rock. In such a way he could easily calculate the relative losses for other constituents. That this method does not give us the absolute losses is perfectly clear to everyone and in the present paper the author has attempted to calculate the absolute losses by a direct measurement of the pore space of the altered rock.

Besides this particular aspect of the question (i.e. losses), the study of the process of weathering of granite is of a great interest from the point of view of the origin of kaolinite deposits. No complete solution of this interesting problem has been yet achieved and although the present work can contribute but little to the enormous existing literature on the subject still it may perhaps give some support to one of the theories of kaolinite formation.

The granite outcrop forming the central and the most elevated region of the Cheviot Hills is thickly covered by glacial drift and peat and can only be seen in comparatively few places mainly in beds of streams and rivers. It is a redish granite fresh in external appearance but under the

microscope it is seen to be nearly always highly altered. Its constituent minerals are quartz, orthoclase, acid plagioclase, biotite augite and micropegmatite in the ground-mass.² The felspars, even in the freshest specimens are usually sericitized.

In regions of the greatest development of moorland peat the granite is invariably covered by a thick layer of boulder clay. This precludes the possibility of studying the action of peat on the granite *in situ*. On the other hand the drift contains besides numerous fragments of Cheviot lavas and some other rocks, many boulders of the Cheviot granite which affords the possibility of such a study.

To the south of the main Cheviot massif, in a col (Scotsman's Knowe) situated between the heads of Harthope Burn and Breamish, a thick (up to 15 feet) deposit of peat is resting on the boulder clay. This boulder clay, unlike that of the lowlands, is very sandy and pervious to water. Some fine sections of the boulder clay, together with the overlying black peat, are revealed in the course of canyon-like ravines typical of all the moorland peat districts. Immediately below the peat all the fragments of the granite in the boulder clay are completely bleached and transformed into a light porous stone. The degree of bleaching decreases as one proceeds downwards, and at the distance of 4 feet below the peat the granite fragments are only covered by a thin coating of bleached material. All the small fragments in the upper portion of the boulder clay are completely bleached, but larger pieces show a pinkish internal portion of partially altered granite. Only very large boulders show a solid core of reddish granite, similar to that found in the original outcrop.

Several micro-sections were made from a boulder showing a gradual peripheral weathering. A section of the inner compact portion shows that it is composed of normal Cheviot granite, in which all felspars are completely sericitized and the ferromagnesian minerals are decomposed into chloritic material and hydrated iron oxides. Biotite flakes can be discerned in few places. The specific gravity of this

compact portion is 2.649 and its porosity - 0.20 per cent (The specific gravity of the Cheviot granite from Breamish Burn varies from 2.65 to 2.69)

Towards the periphery this rock passes gradually into a highly porous pinkish white crust. The outer portion of this crust examined under the microscope is seen to consist almost entirely of quartz grains and flakes of white mica with little of the biotite present. Its mineral specific gravity is 2.597 and its porosity - 18.50 per cent. On boiling the sample does not disintegrate but the water became coloured with humic acid which is le afterwards precipitated by hydrochloric acid. The outermost portion of the crust in the sample investigated was about one sixth inch in thickness, and separated from the inner weathered portion by a thin layer of secondary enrichment of iron oxides. Its colour is almost pure white. Under the microscope (crushed) nothing but white mica and grains of quartz are to be seen. A careful search for determinable kaolinite proved fruitless.

The chemical analysis of the white outermost crust of weathering is as follows

SiO ₂	70.67 per cent
Al ₂ O ₃	20.57
Fe ₂ O ₃	0.29
MgO	0.31
CaO	1.16
Na ₂ O	1.31
K O	3.02
CO ₂	tr
+H ₂ O (+volatiles)	1.78
H ₂ O	0.57
Total	99.68

Porosity 18.50 per cent
Mineral Specific Gravity 597

As one can see over 90 per cent of the rock is composed of silica and alumina. The amount of water (in relation to Al₂O₃) is far too small to give a molecule of kaolinite, but quite sufficient for that of mica.

A comparison of this analysis (taking into the consideration the determined porosity of the weathered rock) with that of the parent rock would easily show the relative losses for each constituent but as no absolutely fresh granite was present among the boulders of the clay it was decided to use some already published analyses of the Cheviot granite from some other locality.

It is true that Cheviot granite shows a certain variability in mineral composition and texture but as far as one can judge its chemical composition is fairly constant. For comparison an analysis of a coarse grained Cheviot granite as given by H. Kynaston¹ was taken. As the pore space of the fresh granite is negligible only the pore space of the altered rock was taken into consideration and its analysis was recalculated accordingly. In doing this we have avoided the initial mistake of taking the amount of Al_2O_3 as constant in both analyses. The following table shows the results of this calculation —

	I	II	III	IV	V
SiO_2	67 12	57 55	—9 57	14 25	116 6
Al_2O	20 12	16 75	—3 37	16 75	120 0
$\text{Fe}_2\text{O} (+ \text{FeO})$	3 99	0 24	—3 75	94 00	1663 0
CaO	1 79	0 94	0 85	47 50	190 5
MgO	0 82	0 25	—0 57	69 50	328 0
Na_2O	1 53	1 07	—0 46	30 10	143 0
K_2O	3 38	2 46	—0 92	27 20	137 3
SO	0 05	—			
CO_2	0 03	—			
H_2O	1 01	1 92	+0 91		
Pore Space		18 50			
	99 84	99 68			

- I Fresh Granite Staindrop Rig (An by I Macadam)
H Kynaston
- II Altered Granite Scotsman's Knowe
- III Loss or gain of each constituent
- IV Losses expressed in percentages of the fresh rock
- V $\frac{\text{Fresh}}{\text{Altered}} \times 100$

Arranging the constituents in the order of their relative losses, we get the following table

$\text{Fe}_2\text{O}_3(\text{FeO})$	94.00	per cent
MgO	69.50	"
CaO	-47.50	,
Na_2O	30.10	"
K_2O	27.20	"
Al_2O_3	-16.75	"
SiO_2	-14.25	"

This table clearly shows that iron oxides and the alkaline earths have sustained the greatest losses while the alkalies have an average loss of 30 per cent and the amphoteric oxides (Al_2O_3 , SiO_2) of about 15 per cent.

The selective leaching of various oxides can easily be accounted for by the nature of the percolating solutions coming from the overlying peat. It is a well-known fact that, the so-called, humic acids readily form salts of iron, alkaline earths and alkalies. Besides the humic acids the peat water probably contains also carbon dioxide sulphuric acid, etc. The combined action of these acids was probably responsible for the leaching out of metallic oxides. SiO_2 and Al_2O_3 , being amphoteric i.e., capable of forming acids, could probably not act as bases towards such weak acids as humic and carbonic acids, and were probably carried away as complex hydrates (silicic and aluminic acids) or as soluble alkaline salts. In a recent paper⁴ the author suggested that the colloidal humic sols could exercise a protective action on the newly formed colloidal alumino-silicic acids. This is why perhaps in our case the colloidal alumino-silicates were not precipitated as kaolinite but were completely leached out.

As was pointed out already, the residual products of weathering consists essentially of quartz grains and white mica. As these constituents occur in the form of minute particles, mechanical separation would lead to no definite results. The only way to estimate their relative proportions is to recalculate the chemical analysis into standard mineral molecules. The results of this recalculation are shown on the following Table.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	H ₂ O	Pore-Space	Total
Muscovite	7.41	7.12	—	—	—	—	2.38	0.89	—	17.80
Paragonite	6.23	5.21	—	—	—	1.07	—	0.62	—	13.13
Phlogopite	0.37	0.08	—	—	0.25	—	0.08	0.04	—	0.82
Margarite	2.00	3.40	—	0.94	—	—	—	0.29	—	6.63
Total Mica	16.01	15.81	—	0.94	0.25	1.07	2.46	1.84	—	38.38
Fe₂O₃	—	—	0.24	—	—	—	—	—	—	0.24
Quartz (SiO₂)	41.54	—	—	—	—	—	—	—	—	41.54
Pore-Space	—	—	—	—	—	—	—	—	18.50	18.50
Total	57.55	15.81	0.24	0.94	0.25	1.07	2.46	1.84	18.50	98.66
Analysis	57.55	16.75	0.24	0.94	0.25	1.07	2.46	1.92	18.50	99.68
Difference	—	—	0.94	—	—	—	—	0.08	—	1.02

This recalculation was done by assuming that all the basic oxides and Al_2O_3 enters into the composition of mica which is taken to be an isomorphous mixture of the following theoretical mineral molecules

Muscovite— $2\text{H}_2\text{O K}_2\text{O 3Al}_2\text{O}_3 6\text{SiO}_2$

calculated from K_2O (minus a certain amount of H_2O allotted to Phlogopite)

Phlogopite $3\text{H}_2\text{O K}_2\text{O MgO Al_2\text{O}_3 7\text{SiO}_2$

calculated from MgO

Paragonite $2\text{H}_2\text{O Na}_2\text{O 3Al}_2\text{O}_3 6\text{SiO}_2$

calculated from Na_2O

Margarite— $\text{H}_2\text{O CaO 2Al}_2\text{O}_3 2\text{SiO}_2$

calculated from CaO

The small amount of Fe_2O_3 was not included into the composition of mica as it probably forms not only biotite but exists as a hydrated iron oxide

The results of this recalculation gives us the total mica to be 38.38 per cent. The remaining silica is taken to represent quartz (41.54 per cent). Considering the pore space we see that the calculated composition of the rock gives us approximately 50 per cent of mica and 50 per cent of quartz.

The calculated composition of mica is as follows

SiO_2	41.75 per cent
Al_2O_3	41.20
MgO	6.5
CaO	4.5
Na_2O	7.0
K_2O	6.41
H_2O	4.75
	100.00

The amount of Al_2O_3 is rather high, but otherwise this analysis is within the limits of probability

Assuming that quartz in the parent granite has been but slightly affected by weathering and therefore its amount is the same in both rocks we can take it that 60 per cent of the remaining minerals (feldspar biotite pyroxene) were transformed into 40 per cent of mica and 20 per cent of the material leached out.

The composition of the leached out portion can be easily calculated from the previous data and is as follows

	Per cent	M I
SiO ₂	49.13	0.8180
Al ₂ O ₃	17.28	0.1695
Fe ₂ O ₃	19.2	0.1200
CaO	4.36	0.0780
MgO	2.92	0.0723
Na ₂ O	2.36	0.0501
K ₂ O	4.72	0.0381
	100.00	

Contrary to all expectations the alkalies are present in very small amount in the leached out portion while silica forms nearly 50 per cent of the total amount. The recent work on this subject by V. P. Smirnov⁵ seems to show that the alkalies are readily leached out from silicates under the influence of humic acids while silica is more insoluble. Those results cannot be considered to be absolutely incompatible with ours if we take into consideration that the natural processes may involve many more factors (nature of solution time etc.) than those in the laboratory.

It is interesting to notice that in this computed analysis the oxides exist in such molecular proportions as to form definite stoichiometric compounds. Subtracting from the molecular proportions for silica an equivalent amount to form with basic oxides compounds of the type R₂O SiO₂ and R₂O₂ SiO₃, the remaining silica together with the sesqui-oxides (Al₂O₃, Fe₂O₃) will satisfy the proportions for the compound of the type R₂O₂ 2SiO₃ (the type of kaolinite—2H₂O R₂O₂ 2SiO₃). Those relations may perhaps not be entirely accidental.

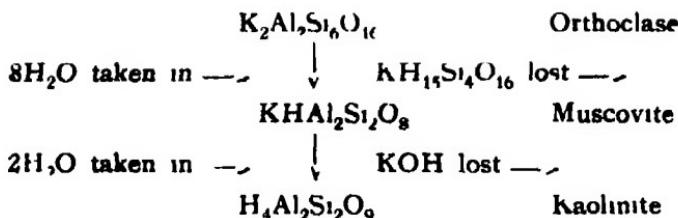
The question of the nature of the process of weathering of acid igneous rocks under peat and similar substances is of some importance in connection with the long debated controversy on the origin of kaolinite. It is a well known fact that kaolinite deposits in many regions such as Germany and U.S.A. are found in close association with coal of the Carboniferous age or brown coal of Tertiary age. Kaolinite is also found in sedimentary rocks associated with

coal deposits (in sandstone of the Coal Measures and in filling cracks in the clay-ironstone septarian nodules) A great number of persons uphold the so called "moor water" theory of kaolinite formation The kaolinizing agency of the moor water, i.e., water charged with the products of organic decay such as humic acids, etc., is either attributed to the organic acids themselves, or to the carbon dioxide in solution, or to both

The majority of the German kaolinite deposits are found in association with the Tertiary brown coals Certainly those kaolinite deposits cannot be fairly well compared with the products of weathering under the peat of recent age, simply on account of their superior age But at the same time we can assume that the processes going now under the influence of peat are comparable to those of the first stage of the brown coal formation

K Endell, who has studied the weathering of basic rocks under peat covering, came to the conclusion that this weathering tends in the direction of kaolinite—“Durch die Überlagerung von Torf, Braunkohle und Steinkohle werden basische Eruptivgesteine in allgemeinen in der Richtung auf Kaolin zu versezt”⁶ On the other hand, in their recent paper on the weathering of granite under the peat, E Blanck and A Riese⁷ have definitely shown that in such circumstances there is appreciable kaolinization The same conclusion is reached by the present writer in the case of Cheviot granite But this by no means invalidates the “moor water” theory of kaolinite formation, but, as we will endeavour to demonstrate, rather tends to support it

Quite a number of authors, such as St J Thugutt, V Selle, G Hickling, as well as the present author, have expressed the opinion, that muscovite (ericite) is an intermediate product of weathering of felspar into kaolinite Without considering for the present the agents of such a transformation, we may represent the process of weathering in the following manner



This process is really that of a progressive hydration, with the resulting splitting of felspar molecule and subsequent removal of alkalies and silicic acid.

In the case of weathering of Cheviot granite we find that the leached out portion contains a very large amount of silica and comparatively little alkalies. This fact can be quite satisfactorily explained by the above scheme of transformation. In the case of the Cheviot granite we therefore observe the first stage of the transformation of felspar into kaolinite with the resulting formation of muscovite. At the same time we can also easily reconcile the two contradictory statements—that of Selle, that under the influence of peat, rocks tend to be transformed in the direction of kaolinite, and that of Blanck and Rieger that under this influence no kaolinization is observed. Kaolinization determined by the progressive hydration depends on the time the rock was subjected to the influence of kaolinizing agents. Therefore we cannot expect to find kaolinite as the result of weathering of rock under a comparatively young (post glacial) peat deposits, while we find it under older deposits of organogenic origin, such as the Tertiary brown coal.

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A PRELIMINARY ACCOUNT OF THE DYKES OF NORTHUMBERLAND

By G. S. MOCKLER

From a consideration of the distribution and direction of the North Country dykes it appears that two sets can be distinguished, namely

A—a set having a general trend east south-east

B—a set having trend east-north-east

The area in which the dykes are developed extends from the most northerly exposures of the Whin Sill near Kyloe as far south as the Cleveland Dyke, with possible extensions to the west into Scotland

Set A comprises the solitary dykes of Geikie (including the Acklington Dyke and the Cleveland Dyke), together with a group lying almost midway between these, which has a marked individuality

In Set B are included two echelon series, one from Holy Island westward to Coldstream, the other from near Alnwick in a south-westerly direction to Falstone, together with various dykes to the east of the Whin Sill escarpment and in the coalfield

All the dykes in the area are composed essentially of plagioclase, pyroxene and ore minerals, mostly fine in grain and from light to dark grey in colour. As a whole they show a rather monotonous similarity, but some types have phenocrysts of plagioclase or amygdaloidal infillings

Microscopically the two sets differ markedly in the mutual relationship of their components

In Set A the plagioclase and the pyroxene minerals tend to develop in relatively long crystals, often with ragged sides, the felspar being embayed by the augite. Frequently both crystals are seen to radiate from a centre forming a coarse variation of spherulitic structure

The ore minerals appear as tiny crystals in the mesostatic material and seem to form rather late in the sequence of crystallization—the appearance prevented by this almost opaque mesostasis is distinctive.

Many members of this set are characterized by the presence of large phenocrysts approaching anorthite in composition.

The set can be divided into two sub-groups—the basaltic and the andesitic—both of which can be matched by rocks from Mull, where they are developed in much greater numbers.

Set B very closely resembles the most usual types of Whin Sill in appearance and composition: with the three minerals—pyroxene, plagioclase and ores developed approximately to the same size. The small amount of mesostasis appears quartzo-felspathic in character.

Micrometric measurements show that in the Set A the pyroxene exceeds or equals the plagioclase in proportion, while in Set B the plagioclase is very definitely in excess.

POMPEII AND OSIIA¹

By DR NORMAN GARDINER

One of the chief lessons that recent excavations have taught us is that ancient life was as varied as our own. The typical Roman house that generations of examiners have been asked to describe is an abstraction as vague as or even vaguer than the typical English house. The house of a country town is not the same as the city house; the town house is not the same as the country or seaside villa; the villa of Italy is different from the villa of Britain. Even in the same town hardly a single house conforms to type. Of this variety no better illustration can be found than a comparison of Ostia and Pompeii. Less than 150 miles apart, they both are situated close to the sea; they both have the usual public buildings, *fora*, temples, *palæstræ*, baths. There the likeness ends. They differ in their history in the characters of their population as in the manner of their destruction.

Pompeii lies on a spur of Vesuvius overlooking the city of Naples which at the beginning of our era was perhaps more beautiful certainly more prosperous and more thickly populated than it is to day. It was a district old in history and legend. For centuries Vesuvius had slumbered, its slopes were covered with groves and villas, even its crater was so thickly overgrown that thieves and brigands found shelter in it. To the north of the bay lay Cumæ, the oldest Greek colony in Italy. At its northern extremity was Misenum, the landing-place of Æneas and now the headquarters of the Roman fleet. Within the bay were Baiae, the fashionable watering-place of Rome.

¹ A paper read in Armstrong College, February 19th, 1927, before the Northumberland and Durham Classical Association and the Archaeological Section of the University of Durham Philosophical Society. The paper was copiously illustrated with lantern slides.

with its palaces built out into the sea, Puteoli where St Paul landed, the greatest seaport of Rome during the republic, Naples, "the new city," so called to distinguish it from the old Greek colony farther north, though now it was no longer new. On the slopes of Vesuvius were the ill-fated Herculaneum and Pompeii. Inland stretched the plain of Campania, a plain famed for its vineyards, for the wool of its sheep, for the luxury of its cities.

Pompeii itself had been occupied for centuries. Its earliest building is an old Doric temple that cannot be later than 600 B.C. The place owed its beginnings probably to trade. It was an ideal place for a trading staple, close to the sea, close too to the River Sarno which brought the rich produce of the interior to the coast, where native Oscans traded with merchants from Etruria, Phoenicia and Greece. In the sixth century it passed under the power of the Etruscans. When they were expelled, the hardy Samnites from the mountains seized the town, and under them it thrived. Many of the houses and large parts of the city wall were built by them. After the Samnite War the town became subject to Rome, but preserved its local government. In the Social War, however, it sided with the democratic party, was besieged and captured by Sulla, who established there a colony of veterans under the proud title of *Colonia Cornelia Veneria Pompeiana*.

At the time of its destruction in 79 A.D. Pompeii was a thriving country town of some 20,000 inhabitants. Oscans, Greeks, Etruscans, Samnites, Romans had all helped to make it, and all who settled there prospered. Wine, oil and wool were its chief sources of wealth, and many of its inhabitants had farms and villas in the neighbourhood. Others enriched themselves by industry—the weaving of cloth and dyeing the manufacture of jewellery and perfumes, metal work of various kinds. Many had shops attached to their houses. They traded with the cities of Campania and with merchants who came from all parts of the Mediterranean. Thus there arose a population of prosperous *bourgeois*, traders, merchants, bankers, retired

officials men of education who liked to live in comfortable and elegant houses and to surround themselves with beautiful and artistic objects men too not over rich nor too much engrossed in business but with means and leisure to enjoy life—a pleasure loving joyous southern folk not too nice perhaps in point of morals And their town was a pleasant place to live in with three large public baths each of them a sort of club two theatres and an amphitheatre capable of holding many more than the whole population

Pompeii perished suddenly on August 24th 79 A.D. and its interest for us is that its excavations reveal the actual life of a small country town just as it was at the moment of its destruction We can read the inscriptions on walls some of them written perhaps the day before We see the shops just as they were left when the inhabitants fled wine jars and cooking utensils lying in their places even the money on the counter of the restaurant Here we see a new temple still uncompleted here an old building being restored

Most of Pompeii was excavated in the last century and has long been familiar to us but it is only within the last few years that we have been able truly to realize the appearance of its streets This is due to the modern horizontal method of excavation The old excavators destroyed as much as they revealed the modern excavator by removing horizontal layers is able to note the position of every fragment to preserve and restore as he proceeds Once we were accustomed to picture the streets of Pompeii as consisting mostly of one storied houses facing inwards with only a few small windows looking out on the streets and certainly the chief impression produced by the narrow streets of the old excavations is one of monotony But when we pass the barrier in the Via dell' Abondanza into the newly excavated part all is changed The houses are mostly two storied some of them standing even up to the roof and instead of a monotonous blank wall we see loggias balconies windows as varied as in a medieval

town. Most of the rooms on the ground floors are used as shops, and the footways are sheltered from sun and rain by red tiled verandas or the balconies of the upper storeys. The walls are gay with paintings, shop signs and inscriptions. Here for example is the shop of a clothes merchant. On one side of the entrance is a picture of Mercury, the God of Commerce money bag in hand coming out of his temple to bring profit to the owner. On the other side is a painting of the patron goddess of the place Venus, in a chariot drawn by elephants. Below these pictures are represented a shop scene and illustrations of cloth manufacture. Here we see a wine jar, strainers and goblets, clearly indicating the entrance of a tavern. Here on either side of the entrance of a private house are painted scenes bearing upon the founding of Rome—Aeneas carrying on his shoulders the old Anchises and leading in his hand the little Iulus, Romulus bearing off the spoils of some robber king. It is the house of one Fabius, perhaps a freedman proud of his connection with the great Fabian family. At the cross-roads is the shrine of the *Comititalia* and over it is a picture of the twelve gods.

All vacant spaces are covered with inscriptions, painted in red letters on a layer of whitewash by the whitewasher or bill-poster (*dealbator*). Most of them are appeals in support of candidates in the local elections, signed sometimes by clubs or guilds, sometimes by individuals. Here is an appeal signed by the guild of fullers, or by the chess-club (*latruncularii*) here a lady solicits votes for her friend. There are advertisements too of tradesmen, notices of lost property or houses to let, programmes of sports in the amphitheatre. Here a street hawker has written his name at a street corner to secure his pitch, or a pair of friends have scratched their names upon the wall to commemorate a pleasant meeting. The habit of scribbling on walls is not confined to the modern world.

The houses are very different in plan, but they have certain general characteristics. They are a combination of the traditional Italian *atrium* and a Greek house. Entering

from the street one passes through a narrow passage into the *atrium*, a square building with the roof sloping inwards and downwards to a square opening in the centre, below which is a square basin the *impluvium*, to catch the rain water. This *atrium*, originally the single room of the house, has been enlarged and divided into various rooms, bedrooms, dining rooms, kitchens ranged round the wall and opening on the central court but this was too straitened a dwelling for the Pompeian. So at the back of the *atrium* he added a Greek peristyle house, consisting of an open court surrounded by a colonnade with rooms opening into it. The court was laid out as a garden, adorned with marble fountains basins, tables, statues. Where space permitted, a larger garden might be laid out behind the peristyle court.

The walls of the courts and of the rooms are all decorated with painting. In the earliest style the walls were painted in imitation of the marble slabs with which the palaces of Alexandria and Rome were lined. Then architectural features were added, columns, architraves, festoons dividing the room into panels, and in the panels were pictures, sometimes large, sometimes small, representing mythological subjects or scenes from daily life. Most of the paintings from the older excavations were removed to the museum at Naples in the new excavations they are all carefully preserved as they were found. There are perhaps no master pieces of art at Pompeii, but there is a surprising quantity of art in the houses, and the generally high standard of this art proves that the inhabitants of Pompeii were men of taste and culture and lovers of art.

Very different is Ostia, though hardly less fascinating. There is indeed little attraction in the flat alluvial plain at the mouth of the Tiber on the south bank of which it is situated, nor does the modern traveller find anything attractive in the dull dusty road that leads to it. It was no pleasure resort, though in ancient days the business men of Rome had pleasant villas along the road and on the banks of the Tiber. Every big city has its suburbs, whatever the character of the country.

The earliest settlement at Ostia was perhaps connected with the salt pans at the river's mouth, the memory of which was preserved in the Via Salaria at Rome, but there was no settlement at Ostia itself till the fourth century, when Rome was first turning her attention to the sea and placed the sign of a ship's prow on her earliest coins. In the middle of this century a military camp was established at Ostia. Its gates and plan can still be traced. The *Decumuna*, a continuation of the Via Ostiensis from Rome, and the *cardo*, were preserved, and determined the orientation of the later city. Its growth began in the third century; for in 267 B.C., four *quaestors* of the fleet were appointed, and one of them was stationed at Ostia, but its real development belongs to the last century of the Republic. Rome was now becoming a Mediterranean power attracting the commerce of all the Mediterranean world. Moreover, Rome was becoming dependent on her provinces for food. The rapid growth of a population at Rome, a population largely unemployed, led to the introduction of the food-dole. Enormous quantities of corn were imported from abroad and sold at cheap rates or distributed gratis in the capital. Puteoli was too far away for the purpose; Ostia was the port to which the corn was brought and where it was stored. So Ostia became the port and emporium of Rome, and continued to be so all through the empire. Rome drew to herself the produce of the world, and all passed through Ostia. Thither came ships bearing marble from Africa, obelisks from Egypt, silks and purples, wines and perfumes from the East, slaves too, and strange animals, elephants and giraffes, lions and ostriches, brought to Rome for the amusement of the crowds in the amphitheatre. Greeks and Jews, Moors and Egyptians, Spaniards and Gauls, jostled one another on its quays.

Yet Ostia was no ideal port. The Tiber is tortuous and its current swift; and only small ships could sail up as far as Rome. Further, the quantities of silt carried down by the river had before the beginning of our era blocked the mouth so that ships could not enter. So they had to

anchor in the open sea and unload their cargoes into lighters, which were towed by oxen and mules up to Rome. Julius Caesar, we are told, meditated making a new harbour, but nothing was done till the Emperor Claudius constructed a circular basin at Porto on the north bank protected by great breakwaters. But the new harbour soon silted up, and Irojan finally added an elaborate octagonal basin connected with Ostia by a canal. So Ostia continued to flourish indeed the city seems to have been almost rebuilt in the reign of Hadrian. Nor did it decline till the fourth century when Rome and her commerce were beginning to decline. Gradually the place was deserted and fell into ruins and the ruin was completed by the raids of the Visigoths. In the middle ages it was used by the Popes as a stone quarry for the buildings of Rome. The castle delle Rovere, which stands at the entrance of the site and is now used as a museum, was built about 1500 A.D. chiefly from materials taken from the ancient city.

Ostia perished gradually so we have no intimate picture of its daily life such as we find at Pompeii, but in its ruins we can trace the story of its growth and its decay. It was from first to last a port, the port of the greatest city of the world, and in this lies its interest. It had under the empire a population of some 80 000 inhabitants but it was not a residential place. Its population consisted chiefly of merchants and bankers, shippers, officials of the customs and police, agents and employees of great business houses, freedmen and slaves. Besides these there was a vast floating population always passing through on their way to or from the capital, and all these had to be catered for. Such a city required very different buildings from those of a small country town.

The visitor who, after seeing Pompeii, comes to Ostia is impressed at once by its spaciousness and regularity. Pompeii grew up out of a country village, and the ground in which it lies is broken—its streets are narrow and irregular. Ostia has been planned. When, after travers-

ing the street of tombs, the visitor passes through the Porta Romana, he sees stretching in front of him, as far as he can see, the Via Decumana, a wide paved street lined with colonnades and fine public buildings. The present street is the work of the empire, and is some two feet above the level of the republican road. Less than half the city has yet been excavated, the portion lying between the Via Decumana and the Tiber--the chief mercantile part of the city.

Some little way down the street on the right behind the theatre is one of the most interesting buildings of the city, the so-called Piazza of the Corporations. It is a square court surrounded by colonnades, and laid out as a garden. In the centre is a temple, which we may reasonably conjecture to have been the Temple of Ceres, for the Piazza is the Corn Exchange of Ostia, the centre of the Roman corn trade. All round the colonnade are the offices of the corporations or guilds connected with the corn trade, and every office has in front of it a mosaic inscribed with the name of the corporation and representing scenes connected with their business. Here we see men pouring the corn into corn measures or unloading a ship; here ships entering the harbour, with a picture of the lighthouse. There are the offices of the tow merchants and rope makers, of the tanners and timbermen. But most of the offices belong to shippers from various parts of the Mediterranean, the shippers of Misua in Africa, of Carthage, of Alexandria, the Karalitani and Turdetani from Sardinia, the shippers of Naibo. Beyond the piazza are great streets of warehouses stretching down to the river. In one of them we can still see the great jars or *dolia*, used for storing the corn, sunk into the floor. The quays themselves have perished long ago, eaten away by the river which has changed its course since ancient times.

We cannot expect to find at Ostia the wall paintings that we see at Pompeii, but Ostia is peculiarly rich in mosaics. In one of the *palæstra* near the Porta Romana is a huge mosaic representing Neptune in a chariot drawn

by four sea-horses at full gallop, while all around are dolphins and strange sea monsters. There is a marvellous vigour and movement in the whole composition. Another mosaic from one of the Thermae shows scenes of country life mules and carts and muleteers, perhaps those who were engaged in carting goods from Ostia to Rome. In the shrine at the barracks occupied by the Vigiles, the fire brigade of Rome a detachment of whom was stationed at Ostia, the sacrifice of a bull is finely depicted.

There is no time to dwell on the forum or the temples which differ little from those of other towns though we may note in passing that Ostia like most seaports was thoroughly cosmopolitan in religion, and that it possessed an exceptional number of temples of foreign gods, especially of Mithras. We must pass on to the houses for here it is that we see the greatest contrast to Pompeii.

In the whole of Ostia there is only one house of the Pompeian type. There is neither *atrium* nor peristyle court in most of the houses. Land at Ostia was valuable, and the Pompeian house required too much room. As we pass along the streets we notice the excellence of the masonry and its solidity, we notice, too, that some of the houses are standing up to the second story that they are lighted from the street by numerous windows, and that many of them have balconies supported on vaulting belonging to the second floor. Originally they must have been four or five storeys high. There is an extraordinary variety of plan. For the most part, however, the houses are built like many medieval Italian houses, round a central courtyard which gives access to the rooms on the ground floor. There is nothing to distinguish the uses of the different rooms as in the Pompeian house. The first floor is reached by a staircase from the courtyard, or sometimes even direct from the street. This and the other floors are very similar in plan to the ground floor, the rooms opening on to corridors running round the interior and overlooking the court. Each floor therefore formed a flat that could be used either for offices or for separate dwellings. Some of these houses may

have been hotels, but there can be little doubt that they represent the tenement houses of which we read in Juvenal and other writers, and that many of the houses which they describe at Rome were of this type. That the type was widespread is evident from its survival in medieval Italy and even in the present day.

PAPERS READ DURING THE SESSION 1926-27

- 1926
- Oct 26th — The Relation of Plants to Habitat By F W Bansome Ph D
- Nov 9th — The Latest Work on the Variability of Atomic Weight By P L Robinson D Sc F I C
- 18th — Weathering of Cheviot Granite under Peat By S Tomkeieff
- 18th — A Petrological Investigation of the Coal Measures Sediments in Northumberland and Durham By J G Kellett M Sc Ph D
- 26th — Integration By R v F H S Jackson MA Sc D
- 30th — Surface Films By T Iredale D Sc F I C
- Dec 9th — Sex in the Campion By K B Blackburn D Sc F L S
- 15th — The Nature of Law in Modern Physics By R G Lunnon MA M Sc
- 1927
- Jan 20th — The Crystal Structure of Iodoform By J F Wood M Sc
- 20th — A Residual Effect in the Actinic Absorption of Chlorine By W Taylor M Sc and A Elliott B Sc
- Feb 3rd — Induced Mutations and their Inheritance By J W H Harrison D Sc F R S E
- 8th — The Constitution of Two Rare Sugars By G C Leitch MA B Sc Ph D
- 18th — Excavations at Pompeii and Ostia By L Norman Gardiner MA D Litt
- 23rd — The Application of Spectroscopy to Molecular Problems By Prof W E Curtis D Sc
- 24th — The Ecology of a Fresh water Phytoplankton By B M Griffiths D Sc F L S
- Mar 7th — The Idea of Cause in its Relation to Natural Law By Dr A C Ewing
- 10th — Some Properties of Cast Iron By C E Pearson M Met

1927

- Mar 10th — The Effect of Water Content on Strength and Specific Gravity of Cement and Mortar " By F Pelton, M Sc
- , 14th — A Contribution to the Petrology of the Whin Sill By S Tomkiewicz
- , 14th — On the Lesser Recognition and Localization of Oil and Starch in some Green Cells after Bleaching with Chlorine Water —By K B Blackburn, D Sc, F L S, and M Thomas, M A
- May 8th — The Philosophical View of the Fundamental Axioms of Modern Mathematical Analysis' By M J Pollard, B Sc, B A
- 27th A Preliminary Account of the Dykes of Northumberland By G S Mockler, B Sc
- , 27th — Recent Palaeobotanical Discoveries in Northumberland By R G Abberlom, M Sc
- , 31st — Recent Advances in our Knowledge of Heredity ' By F A E Crew, M D, D Sc, Ph D

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The objects of the Society shall be :

- (a) The promotion of research;
- (b) The communication and discussion of facts and ideas bearing upon scientific and philosophic questions;
- (c) The exhibition of specimens, apparatus and books,
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Interest	20 0 0	Assistance at Lectures	1 5 0
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		Balance, being surplus from 27th Oct, 1926, to 17th Oct, 1927	83 0 8
			6 6 2
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Surplus at 27th Oct, 1926	£27 9 11	Cash in hand	7 19 4
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			£33 16 1
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Obituary.

THE EARL OF DURHAM

THE Society has sustained a notable loss by the death on Tuesday, September 18th, of its President the Earl of Durham. His Lordship, who served for many years until his death as Chancellor of the University, was elected President of the Society on its reorganization after the War at the meeting held on November 26th, 1919. He took an interest in the Society which could not be measured merely by his attendances at our meetings, necessarily not frequent on account of the calls of a busy life, but it was fitting that as bearer of one of the historic names of the North Country he should be our President as well as Chancellor of the University.

F B

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University of Durham Philosophical Society

THE DISTRIBUTION OF THE MUSSEL BANDS OF THE NORTHUMBERLAND AND DURHAM COALFIELD

By WILLIAM HOPKINS M Sc Ph D F G S

Introduction

One of the most interesting palaeontological features of the Northumberland and Durham Coalfield is the distribution of certain non marine lamellibranchs throughout the Coal Measures. The fossil remains are at times so numerous that they constitute conspicuous bands which have come to be called mussel bands. These bands may be regarded as the remains of old shell banks that existed in the deltas or lagoons in which the Coal Measures were deposited. They are only found in the finer blue or grey shales and are never associated with sandy beds. The presence of sand was evidently unfavourable for their development just as it is to day for their modern counterparts.

Some of these bands can be traced for considerable distances, while others have only a local distribution. The mussels found in the bands belong to three chief genera — *Carbonicola*, *Anthracomya* and *Naiadites*, and can be distinguished according to the positions of the umbones relative to the anterior margin of the shell. In *Naiadites*, the umbones are at the extreme end of the anterior margin, in *Anthracomya*, they are near the anterior end and the posterior margin is expanded, whereas in *Carbonicola*, the umbones approach a position midway between the anterior and posterior margins of the shell.

Other organisms are also associated within the bands, e.g., the annelid *Spirorbis pusillus* (Mart.) may occur independently or attached to the shells. Ostracods are often found in the bands in other coalfields. In this coalfield, there is one Ostracod band above the Harvey seam where it is associated with mussels and annelids, and this band, described in my previous paper, is one of

the most important palaeontological datum beds in our local Coal Measures. Further reference will be made to this band later. In some bands remains of *Calamites* are very common, and it is noteworthy that in some cases as the shales containing these bands become coarser or sandy, the plants become more prominent, until finally a plant bed completely replaces the mussel band.

Non marine lamellibranch zones in other coalfields:

Mussel bands are very common in other coalfields. The late Dr Wheelton Hind advanced the study of the shells constituting these bands by systematising their classification and demonstrating their importance in correlating coal seams, particularly those of North Staffordshire⁸. Mr J. Ward¹¹, and Dr H. Bolton¹³ have also used them for correlation purposes but it has only recently been shown that they may possibly be more reliable than plant remains for zoning purposes. Dr A. E. Trueman and Mr J. H. Davies have effected a revision of the non marine lamellibranchs of the Coal Measures and have demonstrated that they can be used as stratigraphical indices and applied to the recognition of equivalent zones in the South Wales, North Staffordshire, and North of France Coalfields¹⁴. Six zones have been recognized in these fields as follows —

- (6) Zone of *Anthracomya tenuis*
- (5) Zone of *Anthracomya phillipsi*
- (4) Zone of *Anthracomya pulchra*
- (3) Zone of *Carbonicola simili*
- (2) Zone of *Anthracomya modiolaris*
- (1) Zone of *Carbonicola ovalis*

Naming of Species

During the last few years I have been engaged in investigating the correlation of the coal seams of the Northumberland and Durham Coalfield¹⁵. One of the consequences of this investigation was the realisation of the importance of the bands as contributory sources of evidence in establishing correlations. It was found that some of the seams were overlain by shales containing

prominent mussel bands which could be distinguished by the organisms they respectively contained —

1 The band associated with the Brass Thill seam which contains *Carbonicola* with or without *Naiadites*,

2 The band associated with the Low Main seam of Northumberland or the Hutton seam of Durham which contains *Carbonicola* with or without *Anthracomya* and *Naiadites* and in which the annelid *Spirorbis pusillus* is always present

3 The band associated with the Harvey seam which contains an assemblage of *Carbonicola*, *Naiadites*,

Spirorbis pusillus and the ostracod *Beyrichia arcuata*

Mussel bands with the same assemblage of organisms (but without ostracods) were found at other horizons in the Measures, but as far as possible, confusion between them was avoided by reference to other lines of evidence. It was this fact that led me to test the practicability of applying Dr A E Trueman's zonal scheme to this coalfield. Examples of the more prominent bands were forwarded to Dr Trueman for identification and I wish to place on record my indebtedness to him for his kindness in naming particular specimens. These have been tentatively accepted as local standards and the naming of other individuals has been entirely based on the revised nomenclature of Dr Trueman. The primary aim of this paper is to record the results of a preliminary attempt to apply Dr Trueman's zonal scheme to the Northumberland and Durham Coalfield. The results so far achieved are encouraging.

Distribution of genera

The chief horizons at which the more important mussel bands are found in this coalfield are shown in the accompanying diagrammatic Figure which also shows ¹the correlation of the seams in Northumberland and Durham deduced from my previous work². It will be observed that species of *Carbonicola* are more numerous than those of either *Naiadites* or *Anthracomya*. *Naiadites* is fairly

abundant, but *Anthracomya* is extremely rare. This is unfortunate, since in South Wales, according to Dr A E Trueman and Mr J H Davies *Anthracomya* is the most useful genus for zoning the Coal Measures.

It will be further observed that the recorded bands are most numerous in the Measures below the High Main seam of Northumberland and its equivalent in Durham. This is probably due mainly to lack of records. The Measures above the High Main seam are not very productive and it has therefore not been possible to examine them in colliery workings. Mr M Ford in his Presidential Address to the N.E. Institute of Mining and Mechanical Engineers at Newcastle-upon-Tyne, records a complete list of fossils from a sinking recently completed at Washington⁵. An examination of this list however, reveals the rarity of *Anthracomya* above the Three Quarter seam, the latter being the equivalent of the High Main seam of Northumberland.*

Zone of Carbonicola ovalis

It will be observed from the Figure that in the Measures extending from the Hutton seam to the Victoria the majority of the mussel bands contain *Carbonicola ovalis* (Mart.). The Victoria seam with the Marshall Green are the only two workable coals below the Brockwell, the latter being taken as an arbitrary boundary between the Middle and Lower Coal Measures of this coalfield.

I suggest that until other evidence is forthcoming, all the Measures below the Three-Quarter seam be included in the *Carbonicola ovalis* Zone. The upper limits of this zone cannot as yet be defined with any degree of accuracy. Mussel bands are very rare in the Measures below the Harvey seam. This is due to the fact that over a considerable portion of the Field these Measures comprise a thick series of sandstones.

The band above the Harvey seam is not characterised by the assemblage of species belonging to the *Carbonicola ovalis* Zone, but by a number of particular forms which are

*Reference should be made to the Figure for seams recorded at the Three-Quarter

found in the *Anthracomyia modiolaris* Zone of South Wales. This band will be discussed later. This evidence suggests that the lower limit of the *Anthracomyia modiolaris* Zone is probably below the Harvey seam. The exact junction of this zone with the *Carbonicola oralis* Zone in this coal field cannot be recognised owing to the absence of mussel bands between the Harvey and Three Quarter seams.

The known bands below the Harvey do not appear to have a very extensive lateral distribution. Mr Ford has recorded bands above the Victoria and Three Quarter seams at Washington⁵ but as far as I know, they have not been found elsewhere. This also applies to Dr Wheelton Hind's record of a band above the Brockwell seam at Wylam Colliery⁶ which is also a quite isolated occurrence. These bands, however, contain characteristic fossils of the *Carbonicola oralis* Zone. *C. robusta* (Sow.) is confined to the lower portion of the productive Measures. Indeed, the Brockwell and Victoria horizons are the only known examples of its occurrence in this coalfield. Forms of *Anthracomyia* are absent except for *A. minima* (Ludw.) and *A. adamsoni* (Salter). The former has been recorded above the Three Quarter seam at Washington by Mr J. T. Stobbs in Mr Ford's list of fossils, while Dr Wheelton Hind has recorded the latter from the roof of the Brockwell seam at Wylam Colliery.

Zone of Anthracomyia modiolaris

I suggest that this zone begins with its lower limit somewhere between the Three Quarter and Harvey seams (as shown in the Figure) and extending upwards to the Hutton seam of Durham or its equivalent the Low Main seam of Northumberland. Forms of *Anthracomyia* are unfortunately rare, the only known examples in this sequence of beds being *A. modiolaris* and *A. williamsoni* which are found in association with typical fossils of the *Carbonicola semiremis* Zone in the Low Main—Hutton band.

Certain forms, however, which are associated with the *Anthracomyia modiolaris* Zone in South Wales are found in the sequence of beds under consideration. The small and

stout *C. turgida* (Brown) and *C. venusta* (Davies and Trueman) are found, e.g., in the Harvey Beaumont band, while *C. exigua* (Davies and Trueman) occurs in the Low Main Hutton band. This evidence strongly suggests that the *Anthracomya modiolans* Zone includes the series of beds between the Harvey and Hutton seams despite the absence of several species of *Anthracomya* which characterise the zone in South Wales.

The most important band in this zone is that found in the roof of the Harvey seam of Durham or its equivalent in Northumberland, the Beaumont seam. Since this band is also associated with a profuse development of ostracods, I have called it the Ostracod Band. This band is unique in the coalfield, as wherever it is found it shows a constant three-fold division as follows —

(1) An upper division composed of *Carbonicola* and *Nauadites*

(2) A middle division composed of numerous *Spirorbis* and a few *Carbonicola* and

(1) A basal division composed entirely of Ostracods. The particular species found in the band are given in the Figure. No other band of its composite description has been found, as yet, at any other horizon in the local Coal Measures series. It is not the presence of the ostracod *Beyrichia arcuata* (Bean) which makes it distinctive, but the assemblage and order of deposition of ostracods, annelids and mussels. I have traced it from East Holywell in Northumberland southwards to Tudhoe and Bowburn in Durham, and from Seaham westwards to Pelton. It is undoubtedly the most significant palaeontological datum bed in the whole of the Northumberland and Durham sequence of Measures.

The other bands between the Harvey and Hutton seams have not so wide a lateral extension as the Ostracod Band. I have found them at three collieries only—Washington, Usworth and Wheatley Hill.

It will be observed from the Figure that *C. ovalis* occurs in the bands just described. It is not, however,

a characteristic feature In the case of the Harvey-Beaumont band, the chief *Carbonicola* forms belong to the *C. subconstricta*, *obtusa aquilina*, *venusta* and *turgida* types The band is therefore included in the *Anthracomya modiolaris* Zone

The Similis and Pulchra Zones

An examination of the Figure reveals that with the evidence available at present it is extremely difficult to define the limits of the zones succeeding the Zone of *Anthracomya modiolaris*. This is primarily due to the rarity of forms of *Anthracomya* particularly *A. pulchra*, which as far as I know has not yet been found in the local Measures. It will be observed that the mussel bands are most numerous in those Measures extending between the Low Main seam and the High Main seam in Northumberland and between their respective equivalents in Durham. These Measures vary in thickness from 300 ft to 480 feet. Some of the bands found in these Measures can be traced for considerable distances and contain forms of *Carbonicola* and *Natadites* with occasional *Anthracomya*.

Very few bands are known in the comparatively unproductive Measures above the High Main seam, but this may be due as explained previously, to the absence of adequate records. In the higher beds of the coalfield, mussel bands are very poorly represented. It will be observed that *A. philipsi* has been recorded from three horizons in these beds. *C. similis* has been found in many of the bands between the Low Main and High Main seams, but owing to the apparent absence of fossils associated with the Zone of *Anthracomya pulchra* it does not seem at all possible to fix the boundary between the Zones of *Carbonicola similis* and *Anthracomya pulchra*. It is proposed here to group the *Similis* and *Pulchra* Zones together and to refer to them jointly as the 'Similis Pulchra Zones'. It will be shown later that with the present limitation of evidence, one cannot define a satisfactory boundary between the combined zones and the Zone of *Anthracomya philipsi*.

*Description of the more important band, in the Measures,
above the Low Main seam of Northumberland and the
Hutton seam of Durham*

The Low Main Hutton band is one of the most wide spread bands in the coalfield. It has been proved at many collieries in Northumberland where it is generally found some 18 to 20 feet above the Low Main seam. I have found it at many collieries in Durham 1 to 5 feet above the Hutton seam, but have not seen it south of Silksworth⁷. Dr Absalom and I have shown that it outcrops on the foreshore between St Mary's Island and the mainland four miles north of the mouth of the Tyne¹. Where well developed, the band contains abundant *C. cf. similis* (Brown). Other forms include *C. cf. exigua* (Davies and Trueman), *C. cf. aquilina* (Sow.), *C. cf. fulva* (Davies and Trueman), *N. modiolans* (Sow.) and *N. quadrata* (Sow.). Dr Hind has recorded *A. williamsoni* (Brown), *A. modiolaris* (Sow.), and *C. nucularia* (Hind) from the band exposed on the foreshore, below the Waverley Hotel, at Whitley Bay⁸. I have found that it also contains the annelid *Spirorbis pusillus* (Mart.). The assemblage of organisms present in the band may vary from place to place, but *Carbonicola* and *Spirorbis* are always present. I suggest that this band be taken as being at the base of the Measures succeeding the Zone of *Anthracomya modiolaris*.

The Brass Thill—Low Main band of Durham is another band which I have found is very widely distributed. The correlation of the seams with which this band is associated is given in my previous paper⁷. The seams themselves are 35 to 60 feet above the Hutton seam. This band has a greater lateral extension in Durham than that of the Low Main—Hutton Band. I have found it over the greater part of the Durham portion of the coalfield. It is particularly conspicuous in those districts on the south side of the River Wear, where it is found above the Brass Thill seam⁷. It always contains *Carbonicola* with or without *Naiadites* and certain species of *Anthracomya* which at present cannot be identified. *Spirorbis* is never present.

in this band and thus it cannot be confused with the band associated with the Low Main seam in Northumberland and the Hutton seam in Durham. The most common forms present are *C. cf. aquilina* (Sow.), *C. aff. aquilina* (Sow.), *C. cf. acuta* (Sow.), *C. aff. fulva* (Davies and Trueman), *N. carnata* (Sow.) and occasionally *Intracomya* spec.

There are several other bands above the Brass Thill Low Main band each of which is characterised by containing large species of *Carbonicola*, chiefly *C. cf. aquilina* (Sow.). Two of these bands are fairly persistent in parts of the Field. One of these I have found some 20 feet below the Main Coal of Durham, in the Springwell, Seaham, Pelton and Washington districts. The other, the High Main band, is very well known. It is generally found in the shale overlying the High Main Post. It has been proved at the following collieries in Northumberland — East Holywell Fenwick, Earsdon Grange, Bebside, Hartley Hester, Seaton Delaval Forster Newsham Hannah, Cambios, West Sleekburn and Ashington Bothal. Dr R. G. Absalom and I have shown that it outcrops on the south east coast of Northumberland at Seaton Sluice¹.

Mr Ford has recorded bands from the sinking recently put down at Washington which were previously unknown. Many of them are stated by Mr J. T. Stobbs to contain *C. similis* (Brown), using that name in its broader sense. Mr Stobbs has further recorded *C. oratii* (Mart.) not only with *C. similis*, but with *A. philippae*. Forms of *Nasuta* s. are also present with the *C. similis* at Washington.

The highest horizon yet known in the coalfield where *C. similis* occurs is found at Washington, where it is 159 feet below the surface, and 527 feet above the Hutton seam. From an examination of plotted vertical sections of borings and sinkings this horizon is seen to fall approximately within what I have taken elsewhere to be the Lower 70 Fathom Sandstone series². The base of the latter is roughly 520 feet above the Low Main seam of Northumberland and its equivalent, the Hutton seam in Durham.

The only known mussel bands recorded above this horizon in Durham are a band containing *C. aquilina* (Sow.)

some 363 feet above the Hutton seam at Washington and the three *A phillipsi* horizons. The highest beds of all in Durham outcrop on the north bank of the Wear opposite Claxheugh west of Sunderland. They consist of blue shales with bands of clay ironstone. Mr Stobbs discovered *A phillipsi* in these beds in 1906⁹ and in 1919 Dr D Woolacott and Dr C T Trechman described the palaeontological and stratigraphical significance of the discovery¹⁰. The other two horizons at which this fossil occurs are recorded in the Washington sinking at heights of 333 feet and 576 feet above the Hutton seam. At the lower horizon Mr Stobbs has recorded it with *C aquilina* (Sow) and *C tinti* (Kirkby) while at the higher horizon it is found in association with *C orata* (Mart). The lower horizon is some 6 feet above the highest horizon at which *C tinti* occurs and is therefore in the Measures corresponding to the Lower 70 Fathom Sandstone series. *A phillipsi* is thus known to occur in the Measures extending upwards from the Lower 70 Fathom Sandstone series the maximum thickness being 980 feet at Claxheugh. There can be no doubt that the very highest beds of the coalfield are included in the Zone of *Anthracomyia phillipsi* but the lower limits of this zone cannot be defined from the evidence available at present.

The Marine Band at Ryhope

Many years ago Mr J W Kirkby recorded remains of *Lingula* from a band which was encountered during the sinking of a shaft at Ryhope and which he therefore regarded as being of marine origin⁸. The marine band occurs 17 feet above the Five Quarter seam that is to say in measures which in my opinion belong to the Upper 70 Fathom Sandstone series. I have not found the marine band elsewhere in the district nor has any other marine band been recorded from the Productive Measures of the Field extending down to the Brockwell seam.

The isolated Ryhope occurrence may yet prove to be significant for if it could be correlated with a marine band in the coalfields to the south, it might then be possible to

utilise it in the definition of the lower limits of the *Anthracomyia philipsi* Zone. It is very improbable that it is the equivalent of the well known Mansfield Marine Band. If it were, it could then be assigned to the middle of the Zone of *Anthracomyia pulchra*. Until more marine bands are proved in Durham (if they exist there at all) it does not seem at all possible to correlate the Ryhope band with any found in the Yorkshire Coalfield. It should be noticed that Dr Trueman and Mr Davies have recorded a marine band near the boundary of the *Pulchra* and *Phillipsi* Zones in the coalfields of South Wales, North Staffordshire and the North of France⁴.

Base of the Phillipsi Zone

Owing to the rarity of *Anthracomyia* and the absence of any definite marine bands one cannot yet define the lower limits of the *Phillipsi* Zone. There can be no doubt, however, that the very highest beds of the coalfield belong to this zone. The underlying *Pulchra* Zone is in all probability represented by strata but as already stated, no exact boundaries can at present be drawn. The present evidence suggests the grouping of the *Similis* and *Pulchra* Zones together and referring to them jointly as the *Similis* and *Pulchra* Zones. The joint zones may be taken as including all those beds extending upwards from the Low Main seam of Northumberland and its equivalent, the Hutton seam in Durham—probably as far as the marine band and possibly beyond. The highest beds certainly belong to the *Phillipsi* Zone. Between the Three-Quarter or Lower 70 Fathom and Closing Hill seams there is at present no evidence of zonal value.

Zone of Anthracomyia tenui

This zone is unknown in the Northumberland and Durham Coalfield. If the beds included in this zone were ever deposited, they were subsequently removed by denudation before the deposition of the Permian.

Conclusions

1 Owing to the sparsity of forms of *Anthracomyia* it is very difficult to define the limits of the non-marine

lamellibranch zones in this coalfield

2 All the zones recognised in other coalfields by Dr Trueman and Mr Davies are represented in Northumberland and Durham by some part or other of the sequence of deposits, except the Zone of *Anthracomyia tenuis*

3 Despite the rarity of forms of *Anthracomyia* the *Modiolans* and *Ovalis* Zones can be recognised from the presence of fossils with which they are associated in the type district of South Wales

4 The *Modiolans* Zone probably includes all those beds extending downwards from the Hutton seam in Durham to some horizon between the Harvey and Three-Quarter seams

5 It is impossible at present to separate the *Similis* and *Pulchra* Zones in this coalfield on the basis of *Anthracomyia*. It is suggested here that all the Measures above the Low Main seam of Northumberland and the Hutton seam of Durham, except for the very highest beds, be included in the joint *Similis* and *Pulchra* Zones. The highest beds belong to the *Phillips* Zone but the base of the zone cannot be fixed from the evidence available at present

Acknowledgments.

In conclusion I desire to express my sincere thanks to Dr A E Trueman, of University College, Swansea, who so kindly identified many of the species from the more important bands which I had collected from colliery workings. I am further indebted to Professor Holmes for his valuable suggestions and criticisms and for the great interest he has displayed in the identification of the species constituting the bands. I am also indebted to Mr M Ford who kindly presented me with some of the mussel bands collected from the Washington Sinking

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Generalized Section of the Northumberland and Durham Coalfield
showing the horizons of the more important Mussel Bands.

NORTHUMBERLAND		DURHAM	
CLOSING HILL	CLOSING HILL		A. <i>Avellina</i> at Closings
HEBBURN FELL	HEBBURN FELL		
70 FATHOM			
THREE QUARTER	FIVE QUARTER		
70 FATHOM	THREE QUARTER		
THREE QUARTER	SHIFTED ROW		
HIGH MAIN	THREE QUARTER		
METAL COAL	METAL COAL		
STONE COAL	FIVE QUARTER		
YARD	MAIN COAL		
BENSHAM	MADDLIN		
SIX QUARTER	LOW MAIN-MADDLIN		
	LOW MAIN		
FIVE QUARTER	BRASS THILL		
LOW MAIN	MAIN COAL		
	HUTTON		
PIFACEY	RULER		
REALMONT	HARVEY-TOWNLEY		
HODGE	HODGE		
TILFHY	TILFHY		
	HAND COAL		
TOP BUSTY	TOP BUSTY		Boundary of <i>A. mediterranea</i> and <i>L. crenata</i> Zones unknown - may be Lower or Middle bands over this range
BOTTOM BUSTY	BOTTOM BUSTY		
THREE QUARTER	THREE QUARTER		
BROCKWELL	BROCKWELL		
VICTORIA	VICTORIA		
MARSHALL GREEN	MARSHALL GREEN		
Lower Coal Measures continued below Brockwell Seam			Lower Boundary of <i>L. crenata</i> Zone unrecognized

Nice new thickness = 1100 Feet

Thickness = 1400 Feet

Thickness = 200 Feet

Thickness = 170-200+ Feet

Thickness = 100+ Feet

A. *Avellina* at Closings

Marine Band at Ryhope

A. *Avellina*
A. *Avellina*
C. *Avellina*
L. *Avellina*

Mussel bands
with abundance of Cardium
septa + d. *Yarrelliana*
d. *Yarrelliana*

L. *Avellina* w. D.
Spiculae *Primitiva*

L. *Avellina*

L. *Avellina*, L. *Avellina*, L. *Avellina*,
L. *Avellina* A. *Pr.*

L. *Avellina* L. *Avellina* A. *Pr.* + *Avellina*
L. *Avellina* red. w. L. *Avellina*

A. *Mediterranea*, A. *Mediterranea* w.
Spiculae *Primitiva*

Spiculae *Primitiva*

C. *Avellina* C. *Avellina* L. *Avellina*

C. *Avellina* L. *Avellina* L. *Avellina* L. *Avellina*

L. *Avellina* L. *Avellina* L. *Avellina* L. *Avellina*
L. *Avellina* red. w. L. *Avellina* L. *Avellina*
L. *Avellina* red. w. L. *Avellina* L. *Avellina*
L. *Avellina* red. w. L. *Avellina* L. *Avellina*

Spiculae *Primitiva*

Boundary of *A. mediterranea* and *L. crenata*
Zones unknown - may be Lower or Middle
bands over this range

L. *Avellina* A. *Pr.* L. *Avellina*

L. *Avellina* L. *Avellina* A. *Pr.*

L. *Avellina* C. *Avellina* L. *Avellina*

Zone of
d. *Yarrelliana*

Zones of Carbonaceous bands and Anthracite bands

Zones of Anthracite bands

Zones of Carbonaceous bands

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THE RELATIONSHIP OF SOME COMPLEX
NATURAL PRODUCTS TO THE SIMPLE SUGARS
AND AMINO ACIDS

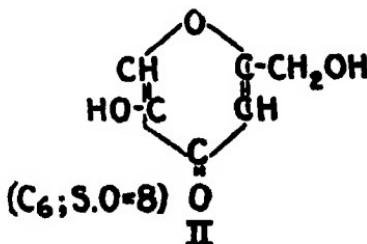
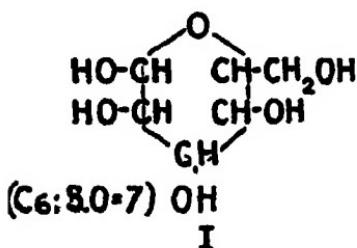
By Prof ROBERT ROBINSON, D.Sc., F.R.S.

*Being the Third Bedson Lecture delivered at Armstrong College
on 9th March 1928*

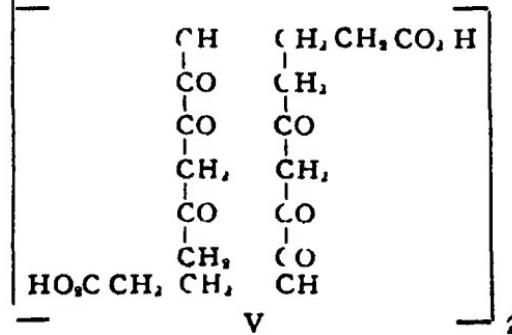
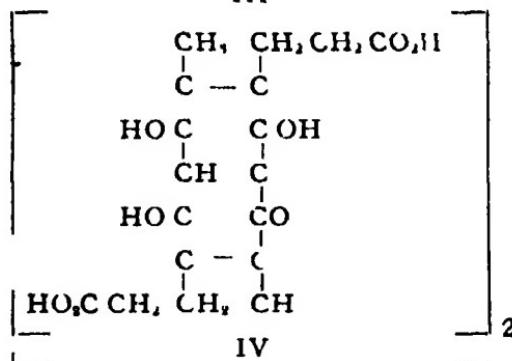
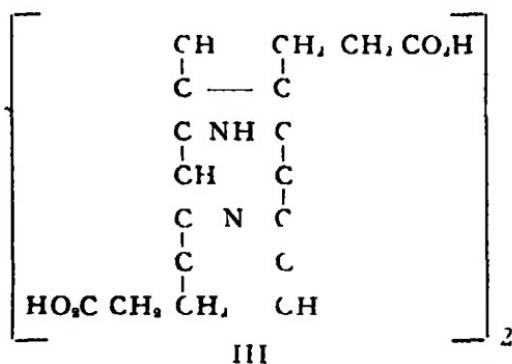
[Abstracted by Robert D. Haworth, M.Sc., Ph.D.]

Whilst many natural products undoubtedly arise entirely from formaldehyde units, it appears probable that other unit structures are employed, and the application of the isoprene unit to terpene chemistry is now so well established that a new terpene structure will not meet with approval unless it can be derived by a fusion of isoprene molecules.

An examination of the structures of animal and plant products indicates that these can be classified according to the length and state of oxidation of the carbon chains. Thus the hexose C₆ group is prevalent and often associated with a triose, C₃, group which probably arises from glycerol. The state of oxidation (S.O.) may be described as the number of hydroxyl groups present in the saturated open chain formula of the substance, the saturation and ring fission being brought by the addition of water. Thus the states of oxidation of the carbonyl group, the carboxyl group and benzene are two, three and four respectively, whilst the state of oxidation of a simple carbohydrate is n+1, where n is the number of carbon atoms in the molecule. The conversion of dextrose (I) into kojic acid (II) by the action of various species of *Aspergillus* involves an increase in the state of oxidation.



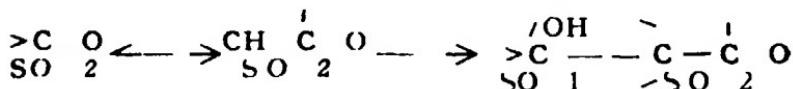
The structures of chlorophyll and haemin provide an interesting case for analysis. The substance (III) can be looked upon as the progenitor from which aetioporphyrin



and chlorophyll are derived by the loss of four and two molecules of carbon dioxide respectively. By abstracting ammonia from (III), structure (IV) is obtained, which, by

the addition of two molecules of water leads to structure (V) consisting of four chains of nine carbon atoms each in state of oxidation of nine. This would suggest that chlorophyll is derived from four molecules of hexose, four molecules of triose, four molecules of ammonia and one molecule of magnesia.

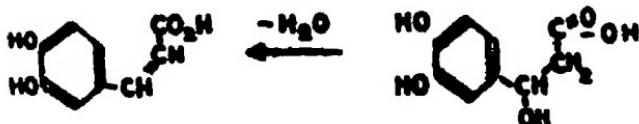
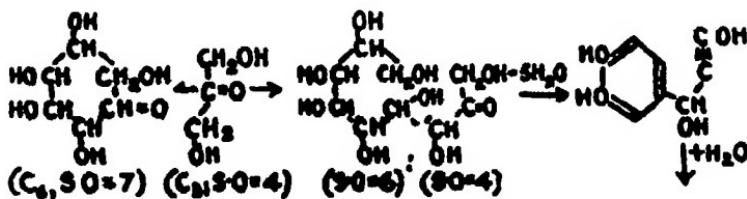
The natural products provide many cases of the association of hexose and triose units cinnamic acid, caffeic acid, coumarin, tyrosine and eugenol being a few of the numerous substances based on the C₆C₃ model. This association is probably the result of an aldol polymerisation. It is to be noted that in this polymerisation the state of oxidation of



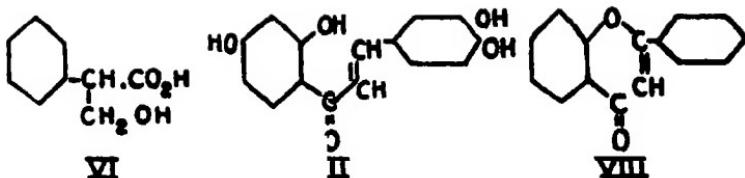
the molecule to which addition occurs is reduced by one unit whilst the state of oxidation of the addendum remains unchanged. In the formation of the C₆C₃ model the triose molecule and the state of oxidation of the hexose portion attaches itself to the hexose and is reduced to six



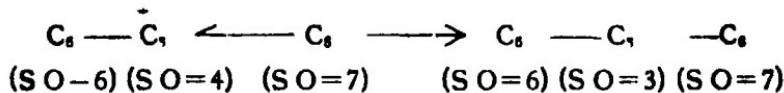
The following formula indicates the process of polymerisation —



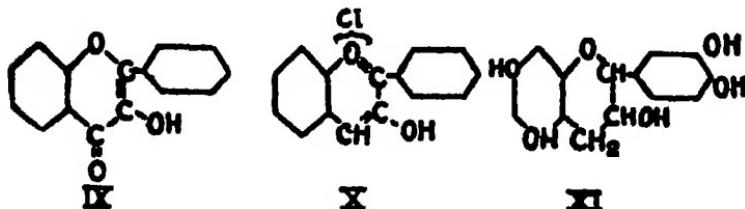
As a rule the triose fragment is present as a normal chain, but in a few compounds e.g., tropic acid (VI), the triose fragment occurs as a branched chain in the C₆C₃ complex.



The flavones, the flavonols, the anthocyanins, also butein, phloretin and catechin are based on the C₆-C₃-C₆ model. As equation A indicates that the hexose portion of the C₆-C₃ complex is rendered incapable of further addition, it is probable that the C₆-C₃-C₆ model is derived by the addition of another hexose molecule to the triose end of the C₆-C₃ model, in which case the state of oxidation of the triose portion will be reduced to three. Such types

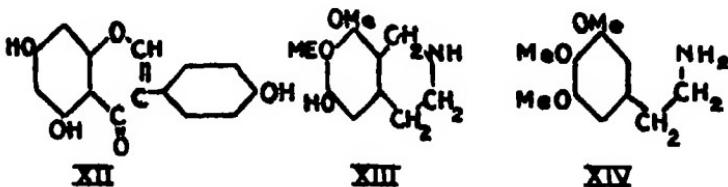


are very common in nature and the groups occur in various states of oxidation, the non aromatic C₃ group exhibiting the greatest variation in this respect. Thus it is normal in butein (VII), oxidised in the flavones, flavonols and anthocyanidins of general formulae (VIII), (IX) and (X) and reduced in catechin (XI), Prunetol (XII) and iridin contain a branched triose chain in their C₆-C₃-C₆ structure.

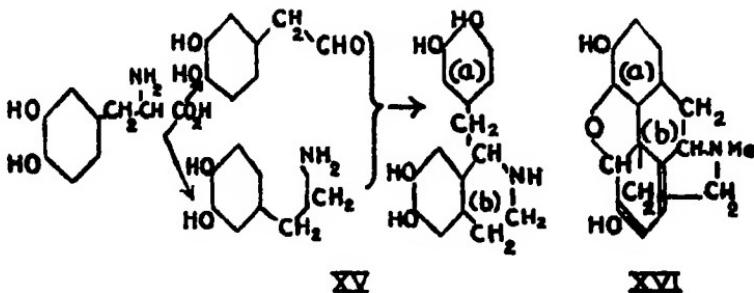


In a similar manner the alkaloids appear to be derived from the amino acids of the C₆ and C₆-C₃ models. The occurrence of simple tetrahydroisoquinoline alkaloids such

as anhalamine (XIII), alongside the corresponding phenylethylamine derivative mezcaline (XIV) suggests that the former arises from the action of formaldehyde on the latter and this process has been performed in the laboratory. The

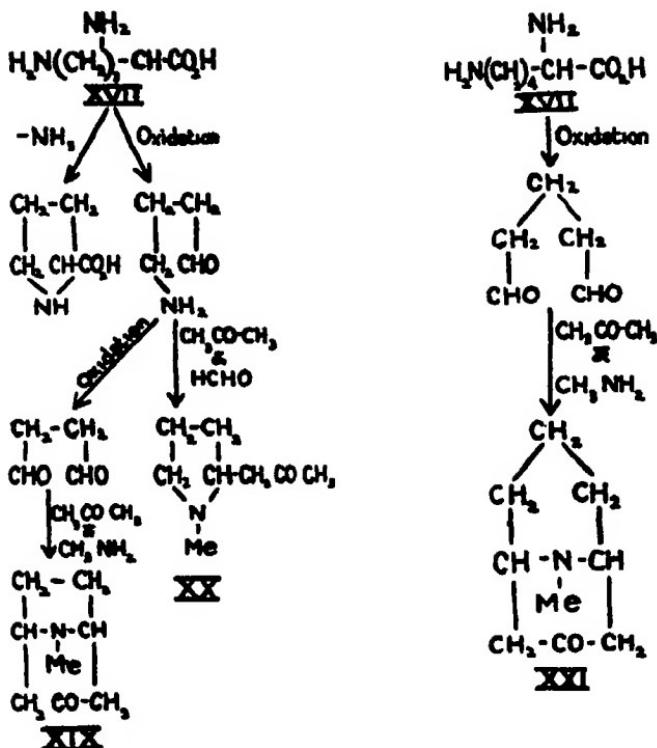


phenylethylamine derivatives and the more complex alkaloids probably arise from amino acids of the Γ C, type and the norlaudanosine structure (XV) can be derived as follows —

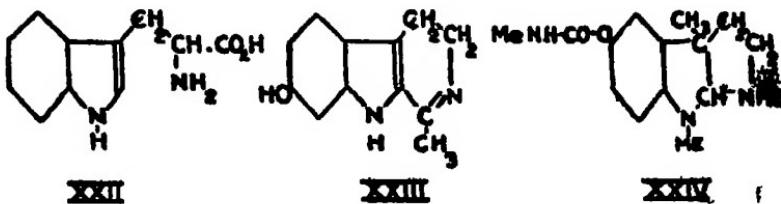


The structures of papaverine, laudanosine, narcotine, hydrastine, berberine and the phenanthrene alkaloids can be derived from (XV), whilst a polymerisation of the two aromatic nuclei at "a" and "b" will lead to structure XVI, which has recently been proposed for morphine.

Other alkaloids can be derived from the amino acids ornithine (XVII) and lysine (XVIII) and the formation of tropinone (XIX), hygrine (XX) and ψ pelletierine (XXI) by the schemes suggested below has been partially imitated in the laboratory.



The ornithine skeleton is also present in histidine, the lysine skeleton occurs in quinine whilst nicotine contains both lysine and ornithine skeletons. Harmaline (XXIII) and physostigmine (XXIV) can both be derived from the amino acid tryptophane (XXII).



It is clear that the foregoing principles are a very valuable aid for diagnosing structures to be confirmed finally by synthesis.

THE APPLICATION OF PHYSICS TO AGRICULTURE FROM THE SIXTEENTH CENTURY TO THE PRESENT DAY

By B A KEEN, D Sc

The Physical properties of soil are of vital importance in cultivation operations, but although the art of cultivation dates from time immemorial and has been brought to a high level of achievement in this country, the science of cultivation does not, as yet, exist. The development of cultivation has been most rapid in the past 100 years, i.e., since the time of the Industrial Revolution in this country. This is confirmed by inspection of agricultural literature since 1534 when the first book on the subject appeared written in English,—FitzHerbert's famous 'Boke of Husbandry'. The introduction of steam power, and in more recent times, the internal combustion engine, raise the question whether rotary tillage of the soil, producing a finely divided state in one operation, will not replace the traditional sequence of operations,—ploughing, cultivating, harrowing,—used at present to produce a seed bed. Experiments have shown that there is little possibility of effecting this revolution in methods until we know much more of the physical and physico-chemical factors concerned in the production of soil tilth. The subject of soil physics has aroused much interest in recent years, because of its direct application to field practice and also because of the need of soil micro-biologists to know more about the physical environment of the organisms concerned in soil fertility. The physical properties of soil are now known not to be simply those of a granular or porous material, there are in addition numerous complex properties due to the existence of colloidal material in the soil, that exert a profound influence on the behaviour of the soil.

THE PROPERTIES OF TORSIONAL VIBRATIONS IN RECIPROCATING ENGINE SHAFTS

By G R GOLDSBROUGH D Sc and H BAKER M Sc, Ph D

(*Abstract of a paper read before the Royal Society, Sept 7th, 1926 Proc Roy Soc, A, Vol 113*)

In the process of calculating the critical speeds at which dangerous torsional vibrations occur in crankshafts the assumption is usually made that the crank, connecting rod, piston rod and piston may be replaced by a flywheel in the position of the crank having a suitable constant moment of inertia. That this assumption is not strictly correct readily appears from the fact that the contribution made by the reciprocating parts varies according to the position in the stroke. It is, therefore, important to find out the degree of error involved in the assumption.

In this investigation a single crank system is examined. For the purposes of clearness and simplicity a model is proposed which embraces all the requisite torsional characteristics of a single cylinder engine except that the gas pressure is excluded. Mathematical formulae are evolved expressing the character of the torsional vibrations and these results are compared with those obtained experimentally by running the model.

The arrangement of the model is shown in Figure 1. The shaft D is firmly clamped to a heavy rotating mass, A, at one end and carries the crank F at the other end. The model is belt driven through the pulley C, and the vibrations are transmitted to a Geiger Torsiograph by the belt G. The crank drives a piston of special design through a long wooden connecting rod.

In the Paper it is shown mathematically and verified experimentally that the effect of the reciprocating masses is to produce a series of speed ranges within which the torsional vibrations are unstable. The widths of the ranges progressively diminish and their values depend upon the relative mass of the piston (in the experiments three different masses were used). The large vibrations occurring in these ranges

have frequencies 1, 2, 3 . . . per revolution. The degree of instability within each range also progressively diminishes with the order of the range: in the experiments only two of the ranges were in evidence.

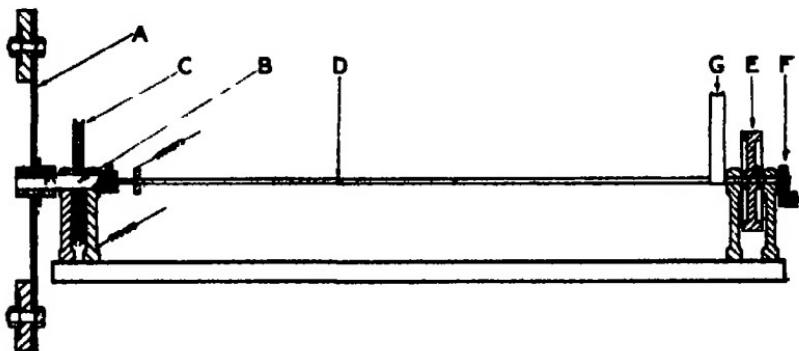


FIGURE 1

Superimposed is a further class of forced vibrations arising from the reaction of the piston mass upon the crank

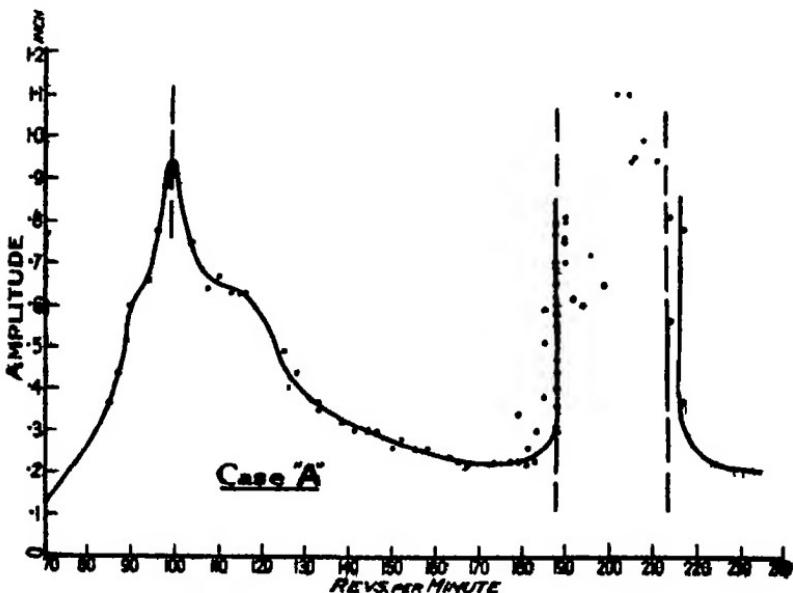


FIGURE 2

and having a frequency of two per revolution. The forced vibrations are quite small in amplitude except in the vicinity

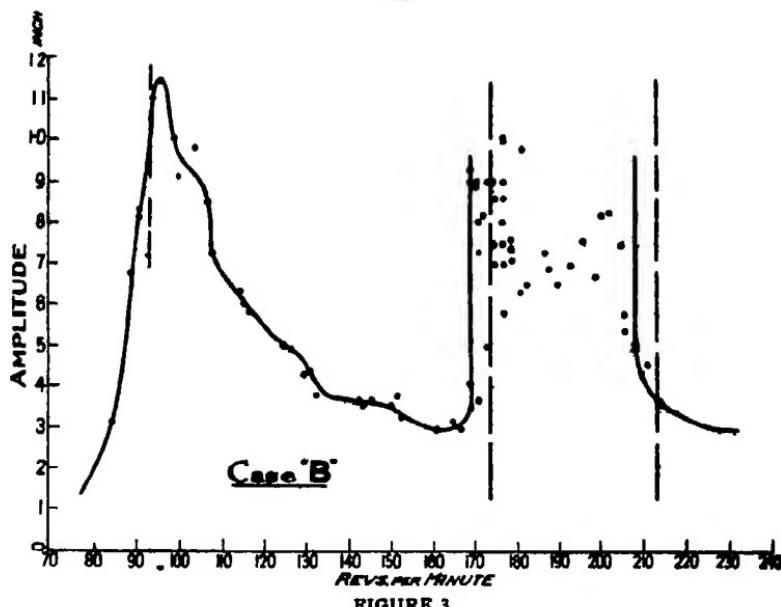


FIGURE 3

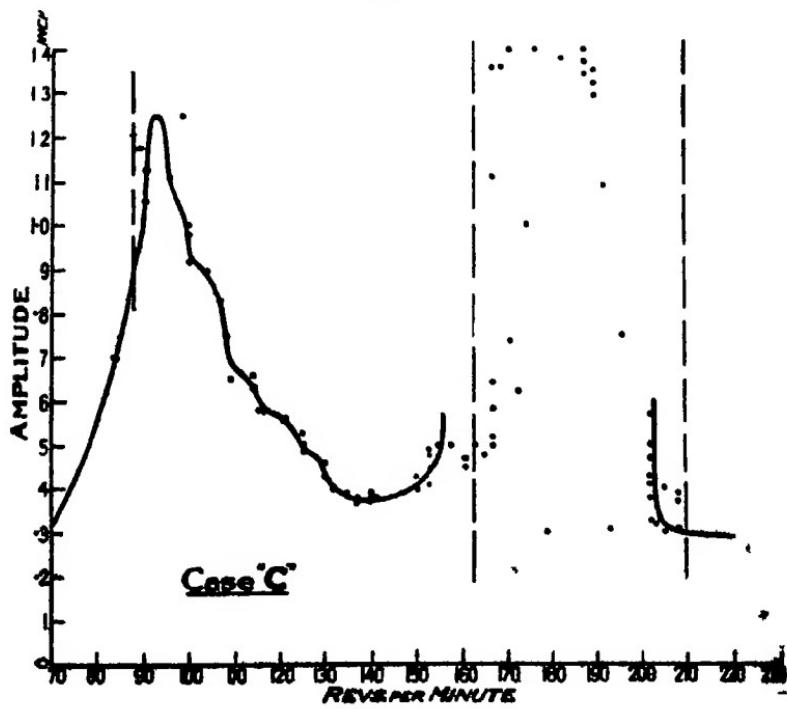


FIGURE 4

of one speed the amplitude being a maximum at that point and diminishing on either side

In Figures 2, 3, and 4 the amplitude of the vibrations recorded on the Geiger Torsiograph is plotted against the speed of the shaft, D , in revolutions per minute It will be seen that in the neighbourhood of two widely separated speeds the amplitude reaches a high value In the figures the solid lines represent the actual results obtained and the vertical dotted lines represent the calculated values The right hand rise of amplitude corresponds to the vibrations of frequency one per revolution and the left hand peak to two vibrations per revolution No trace could be found of the cases of three or more vibrations per revolution

The three figures correspond to three different weights of piston used in the model

RECENT DEVELOPMENTS IN PRACTICAL PLANT FEEDING

By C HEIGHAM M A

In the long run the limiting factor in civilisation and human progress is food supply and food supply depends directly upon the productivity of the soil. It follows therefore, that any large change or any development of science or agricultural practice which makes for increased productivity must rank as an event of first class importance to the human race as a whole.

Agriculture is a very old occupation and it was brought to a relatively high level in the more civilised communities a very long time ago, and it is possible to trace what we are pleased to term modern developments in the practice of men who have been dead for several centuries but despite this we have a right to claim that there have been developments of great importance in the last few years, and that there are good prospects for the future.

In order to see the matter in a proper perspective we must make a short excursion into the past. During the century beginning 1630 a number of philosophers of various kinds set out to examine what they called the "principle" of vegetation. Lord Bacon Van Helmont, Glauber, Boyle and Jethro Tull were men among them whose names have survived. Some thought that water was the sole important factor, others ascribed the magic power of growth to Nitre, "to fire in a fixed state" (whatever that may be) or to earth particles.

The view at the end of the period is summed up by Tull who says "It is agreed that all the following materials contribute in some manner to the growth of plants, but it is disputed which of them is that very increase or food (1) Nitre, (2) Water, (3) Air, (4) Fire, (5) Earth".

From 1730 onwards the general relation of chemistry to many of the problems of plant growth was recognised all over Europe. Experimenters appeared who attacked the matter of plant food from many different angles. A number of other salts beside salt petre were found to have

their effects on plant growth

In 1771 Priestly found that plants take in gases from the air and tend to keep it pure in the animal sense, and so opened up an entirely new aspect of the problem in which the plant was seen to have other feeding organs than its roots alone

After 1804 Saussure introduced the quantitative experimental method and was able to show the absorption of oxygen and the evolution of carbon dioxide by plants and also the decomposition of carbon dioxide and the evolution of oxygen under the influence of light

It was some time before his work had general acceptance and in the interval (1813) Davy had published his work on "The Elements of Agricultural Chemistry"

It will be seen that the slow accumulation of fundamental knowledge was making a foundation upon which a real Agricultural Science could be built up and in 1834 Boussingault in Alsace launched a scheme of work in which field plots and laboratory investigations went side by side and which enabled the problems of plant composition and nutrition to be studied in a systematic manner

He worked out the amounts of carbon, hydrogen, oxygen and nitrogen and mineral matter used by various crops on his land, added the amounts supplied in manure and took the difference as being supplied by air, rain or soil. He also worked out the use of nitrogen by various different rotations of crops and found that some of them left the soil richer for their growth

In 1840 Leibig pushed home the conclusions of Saussure and Boussingault in a famous report to the British Association and it was then generally accepted that the atmosphere was the only important source of carbon for the plant. From this Leibig developed his well known thesis and his law of minimum

"The crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to them in manure—and by the deficiency or absence of one necessary constituent, all the others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indispensable" Leibig

forced home this point and was carried by it a step further, to conclude that plants can derive their nitrogen as ammonia from the air as they do their carbonic acid

This further assumption brought Lawes and Gilbert into the field to prove by large scale field experiments that this was not so and that the nitrogen supplies of the plant came from the soil and mainly in the form of nitrates. The original experiments of Lawes and Gilbert are still going on and they have produced, and are producing a great mass of data upon which the more modern advances of plant nutrition are based. From 1843 till 1900 Lawes and Gilbert worked together in one of the greatest partnerships of practical man and scientist that has ever been known, and through all that long period they continued with patience, ingenuity and set purpose to develop their attack upon the problems of plant nutrition. Quite early in the period they were able to find a commercial application for the discovery that insoluble phosphates may be rendered more readily available to plants by treatment with Sulphuric Acid, and a great deal of the later work both of themselves and their successors has been financed by the proceeds of that discovery.

Despite the commercial turn which the discovery and exploitation of Superphosphate gave to one aspect of their task Lawes and Gilbert continued to work on fundamental lines and not in a narrowed field, and the great and lasting benefits left by their association come from the fact that they sought knowledge for its own sake and without deliberate bias.

It is worth while to remark here, before leaving the historical aspect of the subject, that nearly all the advances that have been made in the knowledge of plant nutrition have come as the result of work in pure science which often enough showed no obvious connection with the subject. Time and again it has happened that the research workers have been held up at what appeared to be the outer edge of knowledge, when some discovery of a new aspect or an improved process made by a worker in pure science has opened for them a whole new field of investigation. Priestley's discovery of oxygen is a case in point, and Sauvage's

Eudiometric method for gas measurement is another while, in more modern times the discovery of soil bacteria and symbiotic organisms is a third

The History seems to suggest that although specialised and applied workers are necessary to explore and exploit such fields of knowledge as are already in view, the great discoveries have come and will come as the result of the work of pure science and the pursuit of knowledge for its own sake

To turn now to the more modern aspects of the problem, as a result of past work we know now that there are five factors which greatly affect the growth of plants and we have some idea of how they work in the plant. They are, water supply, air supply, temperature, the supply of plant food, and presence of injurious factors, and it is within the scope of these five that we must look for recent advances and developments

We know also that the five although producing their individual results are found together in the field and tend to interact in a very complicated manner. We find that although for laboratory purposes the usual type of controlled experiment dealing with one factor at a time remains our standby, it is necessary in the field to consider several variable factors at one time. It is only in the last few years that this has become possible and that as a result of advances in pure mathematics and in the study of statistics

Statistical analysis has been applied to some of the great mass of earlier work which has been accumulated in the older research stations and it has enabled new interpretations to be made of collected results which bring them much nearer to the truth

In addition to this it has brought a possibility for close and accurate experiment in the field which is new, and which enables workers to use field experiments for comparisons in which only small differences are to be expected, and which were formerly confined to the laboratory or the greenhouse

As instances of the use of this valuable development which is associated closely with the names of "Student" and R A Fisher we may take the recent interpretations of the Broadbalk field results of Lawes and Gilbert Fisher

has been able to sort out from the mass of other factors the influence of Rainfall on the Yield of the Wheat and thereby to obtain a very much closer interpretation of the action of the various manurial treatments over a wide range of seasons

It was possible with the older type of field experiment to obtain useful results when the comparative treatments were such as might be expected to give differences of 20% or 30% in yield and a great deal of useful work was done by means of such experiments carried on through a long course of years, but when the main differences had been established and it was desired to get down to close details, field experimenters were brought to a pause by the great amount of uncertainty that existed in the interpretation of the results

By use of the method of statistical analysis coupled with an adequate replication of treatments and a carefully designed lay out of the field plots it has been found possible to deal certainly with differences of the order of 5% and thus a very large new field of work has been laid open for experimenters

Of the five factors having influence upon the growth of plants that of the supply of plant food has received perhaps more attention than the others and a short review of some recent work and opinions will serve to illustrate the trend of progress and to link up the more academic work of the past with practical issues of the present

Nitrogen, Phosphorous, Potash and Lime are the four factors which have received most attention, not because they are more necessary to the growing plant than a number of other substances but because they are the ones which are most likely to become deficient in a cultivated soil and which, in consequence, are of great moment to the commercial grower of plants

To take them in order, Nitrogen starvation is well marked in the field as in water cultures by a general stunting and yellowing of the plant. An addition of nitrate to the starved plant brings at once an improvement in colour and a strong growth of leaf. If all other nutrients are present in sufficient quantity this will result in a general improvement of the plant, but if not the result may only be an increase of

leaf area without a corresponding increase of efficiency in the assimilation rate for carbon This is well shown by Gregory's recent work on barley Increased leaf growth has at times great agricultural value and this is recognised in practice by the increasing use of quickly acting nitrogenous salts as top dressings to growing crops These dressings are of particular value where it is desired to force a crop forward in order to take advantage of a good growing period or where an increase of leaf area may enable the plant to combat successfully some fungus or insect pest which has a relatively short period of attack

The leafage produced by excessive use of nitrogen is characteristic in that it is soft, sappy and very dark green and is particularly liable to attack by insects and by fungus so that in practice the grower may soon meet with the limit to the effect of the nitrogen remedy for such attacks Further it is now well established that extra nitrogen has an effect in delaying ripening, and this in many situations and with many crops, may be a serious matter The nitrogen is generally taken up by the plant in the earlier stages of growth but it has to be translocated to the seed or other food store before the organism ceases vegetative growth and comes to maturity This takes time and where the supply is excessive this will mean delay in the period of ripening A very good case of this was seen in an experiment by Heigham and Page with sugar beet carried out in 1926

Four treatments were given which differed only in the amounts of nitrogen employed These were expressed as — 2N-6N-9N and 12N and were roughly equivalent to 2, 6, 9 and 12 cwt^s of nitrate of soda per acre Each treatment was replicated four times and the whole was set out in what is called a latin square The three last treatments were known to be excessive in amount and the land was in good heart, but it was desired to study their effect rather than to obtain a maximum yield of beets

The yields of roots and tops obtained in tons per acre were —

	Roots	Sugar %	Tops
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2N	15 tons	17 cwt ^s	18.0	25 tons	0 cwt ^s
6N	14 ..	12 ..	17.4	25 ..	6 ..
9N	14 ..	12 ..	16.8	26 ..	0 ..
12N	14 ..	19 ..	17.2	25 ..	13 ..

A usual ratio of root to top in sugarbeet is about 3 : 2 and with a 15 ton crop there would be about 10 tons of tops, but it will be seen that in this experiment the result is very different

In point of fact the beets, although left late into December never showed the common signs of maturity and they were harvested as a still growing crop. The supplies of nitrogen were so large that the plants never succeeded in using them to advantage but in the endeavour to do so went on putting out extra leatage without however, increasing their assimilation efficiency for carbon

Nitrogen, although of course adequate supplies of it are necessary to all plants, has been called 'the manure of the green leaf,' and certainly it finds very valuable uses in those departments of agriculture which are concerned with the production of abundant herbage for animal feeding. Green crops as they are called answer particularly well to it and in the last few years the use of it for grass production has been very much increased. The fact already mentioned that plants generally take up their nitrogen supply early in life has been used to advantage in this, and we find commercial applications of it in grass husbandry in the work of Wagner of Berlin during the war and in much more recent English work of the same kind.

The reasoning underlying this work is as follows — certain types of animal production notably the production of milk and the production of new tissue in growing beasts, involve the use of considerable quantities of protein. In the ordinary way elaborated protein is expensive to buy and the cost of large supplies of it operates unfavourably against profitable animal husbandry. Although protein as such may be expensive, nitrogen as such may be relatively cheap and nitrogen is generally to be considered as the costly constituent of protein. The question then arises how may nitrogen be brought most cheaply to the protein form for the use of the producing animals? If plants can be used so as to elaborate it quickly and cheaply for animal use then this may be the way.

Plants can be so used, especially grass plants, for they take up their nitrogen in the early stages of growth and can

be used while their bulk is still small in relation to their nitrogen content. Further, if ample supplies of nitrogen are available in the soil the plants will recover quickly from the early check by grazing or cutting and will at once begin to take up and elaborate fresh supplies of nitrogen. They will do this all through the growing season and will thus produce a succession of light crops of highly nitrogenous material which is of the greatest value in the production of milk or young flesh.

Provided always that the supplies of other plant nutrients are sufficient and that the water supply and the temperature are suitable it has been found that this system of intensive production works very well and that it enables the amount of milk and meat produced per acre of grass land to be multiplied by two or sometimes by three or four. It has appeared in much recent work that the efficacy of nitrogen as a plant food is bound up with (a) the supply of potash to the plant (this is particularly noticeable in dry seasons) and (b) with the condition of the soil in respect to acidity. Also it has been found that the condition of aeration of the soil is important. Large supplies of nitrogen are wasted if they are applied to water-logged soil, for under such conditions they cannot be elaborated by the action of aerobic bacteria to the nitrate form in which plants can use them. Actually in very wet conditions denitrifying organisms can do more work than nitrifiers and an actual regression of available nitrogen can appear. This mention of bacterial action introduces another aspect of the nitrogen problem which is of comparatively recent development and which is certainly not fully understood at the present time. We know from the work of Nobbe and Hiltner, and others who have followed them, that certain bacteria living in symbiosis with leguminous plants can fix atmospheric nitrogen on the root nodules of these plants. We know also as the result of the brilliant work first of Winogradsky then of Beijernick and a host of others that certain free bacteria in the soil can also use the nitrogen of the air and fix it in their tissues for the ultimate use of plants.

As a result of these discoveries and of observations by practical plant growers we know that full use cannot be made

of nitrogen supplies in the soil unless proper conditions of aeration and temperature are also present. These conditions introduce a very considerable complication in practice and open up a fresh field for investigation of the interaction which must exist between manuring and those acts of cultivation which modify the soil conditions with regard to bacterial life. Work on this subject is proceeding but at present the results obtained are insufficient to admit of any large generalisation.

We can say with regard to nitrogen that the recent work has enabled us to come from the general to the particular and that we now know not only that nitrogen will produce a considerable increase of growth in most crops, but we are able to say with some certainty what that increase will be under any particular set of conditions. This means that we have progressed from an academic to a commercial stage and we can now pause to look at the matter from an entirely different angle.

Having found the uses of the material we can now look to the development of the supplies and we shall find that in recent years great developments have taken place. In former times nearly all the nitrogen used for manuring purposes was in organic form, as farm yard manure or organic residues but with the development of industry and transport, supplies of another kind began to appear in the first half of the 19th century. Coal gas manufacture yielded Sulphate of Ammonia as a bye product. Chile saltpetre began to be imported from the salt deposits in the dry area at the foot of the Andes. These were the first of the artificial nitrogenous fertilisers which came to aid the older supplies. The technique for the use of them was established in due course and their success combined with the growth of knowledge of plant nutrition has given rise to many new supplies. Not so long ago Crookes (1897) drew attention to the fact that the supplies of nitrogen as represented by organic fertilisers and the two others already mentioned were likely to prove inadequate for the world's demand for food stuffs. He pointed out that some 4/5 of the air is free nitrogen and that this represented a supply that might well be tapped to avert the crisis of starvation which he saw

in the future Whether as a result of his warning or not, use has been made in recent years of the atmospheric nitrogen and we now have large supplies of several nitrogenous fertilisers derived from it Nitrate of lime, Calcium Cyanamide and Sulphate of Ammonia are being produced in increasing quantities from atmospheric nitrogen not as bye products of some other trade but as the principle products of great manufacturing organisations The use of them is extending from the European countries and America into the other great plant growing areas of the world where their effect in increasing production is likely to be so large as to alter the whole aspect of the problem of the world's food supply

We may say then of nitrogen that recent work has brought the older discoveries to fruition and that the present time is ripe to be an age of realisation for the dreams of the past Yet while this is so we must admit that we do not yet understand the whole of the problem and that there are always fresh fields for our investigations be they fundamental or particular

The action of Phosphorous in the plant is less obvious than that of nitrogen but it is of the very greatest importance Phosphate starvation is shown by a characteristic reddening or purpling of the green tissues and by stunted root growth This has been known for a long time but it is only recently that Gregory has been able to measure the loss of efficiency in carbon assimilation that accompanies these conditions

A great deal of the soil of the world is insufficiently supplied with phosphates and therefore in practical agriculture a great deal of stress has been laid upon the problems of phosphate manuring

Where the phosphate supply is adequate the ripening process is hastened a little and for this reason dressings of phosphate are used in cold or northerly districts to help to bring the corn crops to maturity before the cold of autumn sets in Russell states that the northern limit of several crops may be extended by the use of extra phosphates Phosphate starvation in some parts of the world, notably in South Africa, is very marked and is accompanied by a

serious alteration in the composition of the crops which greatly lowers their feeding value. In our own country we know that the best pastures for fattening purposes are generally well supplied with phosphate and we also know that additions of phosphate will often bring about a great and beneficial change in the growing herbage.

A great deal of the field work with phosphates on grass has been done by Somerville, Middleton and Gilchrist working from Armstrong College on the Cockle Park farm of the Northumberland County Council. These workers found that on the poor and acid clay of this farm dressings of phosphate either in basic slag or as ground mineral phosphate produced a very marked result in changing the herbage from a mixture of coarse grass and rushes to another of finer grasses and white clover. The change in this case is so remarkable as to be quite obvious even to casual inspection and it is associated with a very great increase in the stock carrying capacity of the soil. The function of the phosphates in encouraging vigorous and early root growth is particularly valuable on strong and cold clays where the mechanical conditions are against the young plant in its endeavours to put out working roots and the need for additions of them is generally found to be more acute upon such soils than upon good sands and loams.

Another aspect of the use of phosphate which may have some bearing upon the success of Somerville and Gilchrist appears in the more recent work of Thornton and Gangoulee with strains of the *Bacillus Radicicola*. These workers found in the life cycle of that bacterium which form nodules on the roots of Lucerne (*Medicago*), definite stages are traceable in which the organism is ciliate and motile and that these motile stages could be prolonged and strengthened by traces of phosphate in the medium upon which the bacteria were living. During the motile stages the bacteria can move about in the soil and spread from place to place and from plant to plant though as yet the area of their perambulations has not been accurately determined. It appears, therefore, that the addition of phosphate to a soil as to a culture may have its effect upon *Bacillus Radicicola* and make that organism more efficient in its search for

young clover roots on which to live If this is true of the strain of Bac Radicicola that lives with Wild White Clover as it is with that found on Lucerne then it may help to account for some of the remarkable results obtained on heavy soils which have natural phosphate deficiency

As with nitrogen so with phosphates, the progress of knowledge to link up with practice has brought a great increase in the supplies available to the farmers and has brought also a growing demand for phosphatic fertilisers from all parts of the world South Africa, Australia and parts of Canada are all beginning to use great quantities of phosphates while the use of them in the older countries tends to increase also The supplies available are in the form of Super phosphates, made generally from rock phosphate treated with sulphuric acid to convert it to a soluble mono-calcic form Basic slag, a bye product of steel manufacture which varies greatly in value according to its exact constitution Ground Mineral Phosphate from the various natural deposits of phosphatic rocks in North Africa, Belgium and America Various bone products

Unlike nitrogen we cannot extract phosphate from a vast atmospheric store and it may happen in the future that we shall have some difficulty in supplying the need of a very thickly populated and intensively cultivated world

Brenchley and Maskell have shown that the action of phosphate is aided to some extent by Silicon but at present nothing has been found to replace it in the plant economy

Potash, according to Russell, produces four distinct effects on the plant —

- (1) On the general health and vigour of the plant
- (2) On the efficiency of the leaves for synthesising and translocating Carbohydrates
- (3) On certain processes occurring in leguminous plants
- (4) On the formation of grain

It is certainly true that plants that are potash starved suffer more from adverse conditions than do others which are adequately supplied with it This is a matter of common observation in years of drought particularly with such crops as potatoes and mangolds

In an experiment with potatoes carried out at Rothamsted in 1925 a year when a strong summer drought was experienced an addition of 2 cwt of Sulphate of Potash per acre brought the crop from 522 tons per acre to 9180 tons per acre an increase of about 90% It has been found also that plants which are short of potash succumb more easily to the attacks of fungi or insects and that they have less recuperative power than others This has been well observed by Bewley with tomatoes under glass who has found that potash dressing helps the plant to resist the bacterial stripe disease

It appears that there is a very close relation between potassium and nitrogen in their action in the plant and the effect of either will depend a great deal upon the balance of the two and a good deal of work is being done at the present time in the endeavour to obtain an exact interpretation of that balance

Beyond the fact that under many conditions added potash will encourage the increase of leguminous plants very little is known of a relation which certainly exists Stoklasa considers this is due to the action of potash in assisting protein synthesis but this is not yet well proven It is certain however that potash starved plants will not form grain well and in severe cases may fail to come to maturity at all

The main supplies of potash are found in mineral deposits in Germany and Alsace and since these have been opened up the use of wood ashes and seaweed the older forms of potassic fertiliser has largely ceased During the war a good deal of flue dust from steel and other works was used

Potash deficiency appears most often on the lighter soils but it does not as a rule appear with such marked effect as phosphate or nitrogen deficiency There has been an increase in the use of potash salts and there may come a time when it will be necessary to augment the existing sources by drawing directly from the sea Quite recently the Dead Sea has been examined with a view to using it for this purpose but no immediate development is expected

The question of lime and the part played by Calcium

in plant nutrition is too big a one to deal with at the end of a paper and it must suffice to say that although all plants contain some calcium in their make up it is as a soil conditioner and an acid neutraliser that it finds its main uses in agriculture. By correcting acid conditions it helps vigorous root and bacterial growth in the soil and by causing flocculation of the very small particles of a heavy clay it helps to improve conditions of aeration in the soil.

The shortage of it is generally more serious on light soils than on heavy ones as in the former there is no clay colloid material to buffer the effects of acid in the soil solution.

The question of lime supply is one that is attracting a great deal of attention at the present time largely because there is a progressive loss of calcium to the top soil. At Rothamsted where there is a good natural supply of Calcium Carbonate in the soil this loss is estimated to be equivalent to 4 cwt of CaCO₃ per acre per annum.

It is obvious that where lime is being used up by crops and there is also this annual loss by leaching, a time will come when a definite shortage will have to be faced. This is not a new fact although now it is expressed in more exact terms than heretofore.

In many of the oldest systems of husbandry of which we have record we find that the farmers have made a free use of quick lime, chalk and marl, and heavy dressings of these materials applied once in 20 years or so were often used. Of late years owing to the increased cost of labour these heavy liming operations have tended to be neglected and in consequence each year finds more and more land showing signs of lime shortage. The modern method of using it is to apply the material in a fine state of division in small quantities once in 4 or 5 years and this avoids to some extent the very heavy outlay of the older systems, but even with this saving the economic position makes it very difficult for the farmer to make proper use of the knowledge that is available.

Looking back over the ground we have traversed we get an impression that the greatest developments in practical

plant feeding in the last few years have been associated with practice rather than with principle

The older research workers succeeded admirably in their primary investigations into the main requirements of plants but they did not for the most part trouble with the practical details. The filling in of these details has been the business of their successors and is still going on, but enough has been done now to bring practice and precept into close touch and to give concrete form to the shadows of yesterday.

The passage of successful results from the laboratory or the experimental plot to the commercial farm or garden has been hastened considerably and now we are beginning to see a really wide application of the principles already established.

There is of course no finality to most problems of biological research and in the case of plant feeding there are great fields of work yet to be exploited and there are probably discoveries in the womb of the future which will revolutionise our ideas of the life of the plant and its requirements as has happened more than once in the past.

In the meantime we have much to do in developing and applying the knowledge already gained.

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THE PLANKTON OF THE RIVER TYNE ESTUARY

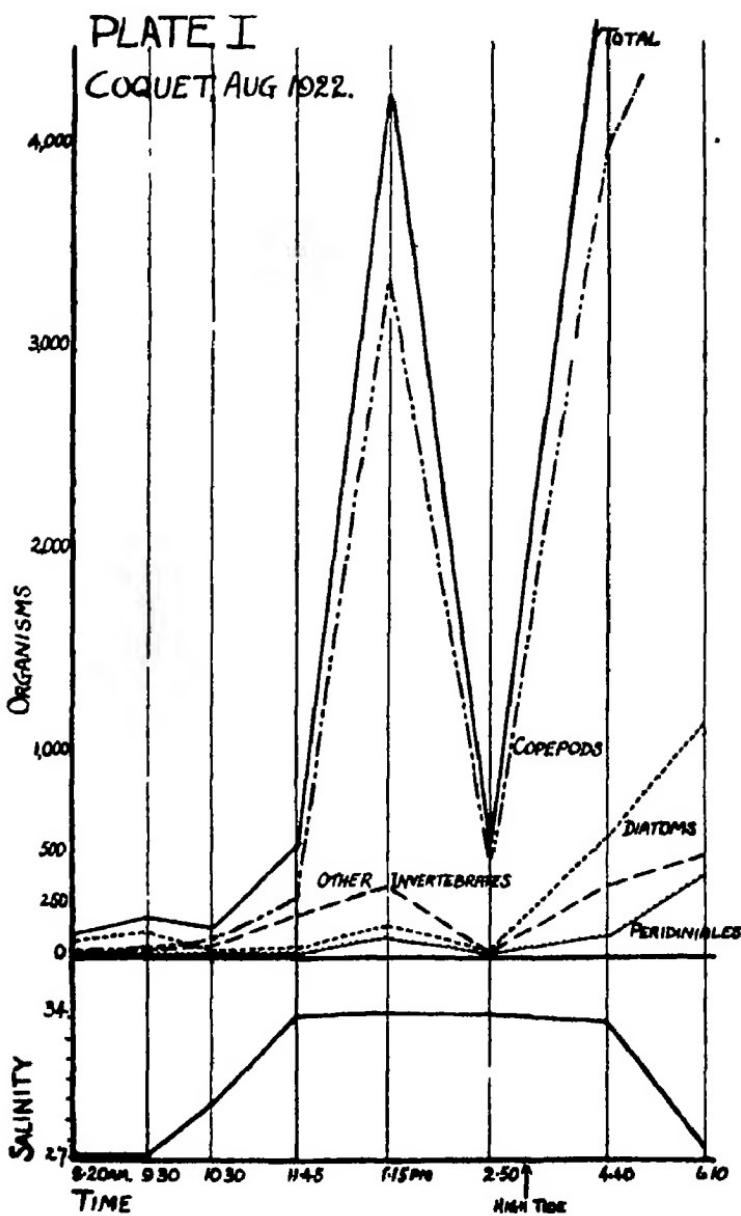
By Olga M. Jorgensen M.Sc.

Plankton samples from the tidal region of the Tyne—from the Black Middens up to Newburn Suspension Bridge, a distance of fifteen miles—were taken during excursions made with the Motor Yacht 'Evadne' from the Marine Laboratory at Cullercoats for the purpose of studying the condition of the river with regard to pollution. These samples, together with a series obtained weekly at the Swing Bridge, Newcastle-on-Tyne, from May to December, 1925, were examined, and it is from the data so obtained that the following account of the floating life of the river is compiled.

The contents of the catches made by the 'Evadne' on May 2nd and July 26th, 1922, have been reported on briefly in the Marine Laboratory Report* but are here considered more fully and in conjunction with those obtained on July 22nd, 1925, and those from the Swing Bridge. Also, as it is difficult to appreciate the extent to which the planktonic life of the river is affected by the great industrial area through which it flows without making a comparison with one not so affected, an account is given of the conditions which obtain in the Coquet.

From an analysis of the data thus at our disposal it is possible to deal with the plankton of the Tyne quantitatively and qualitatively and to indicate its variability due to the condition of the river in relation to temperature, the amount of dissolved oxygen and the state of the tide. A comparison of the species found in the tidal regions of the Coquet and the Tyne will show that while each estuary can be regarded as being "biologically, as it is physically and chemically, an arm of the sea"** the greater length of the estuary and the far-reaching effects of pollution have

* "Estuarine Plankton," by A. Meek, Dove Marine Laboratory, Cullercoats, Report for 1923, pp. 78-91.



masked this very considerably in the case of the latter river. This is indicated in the following table.

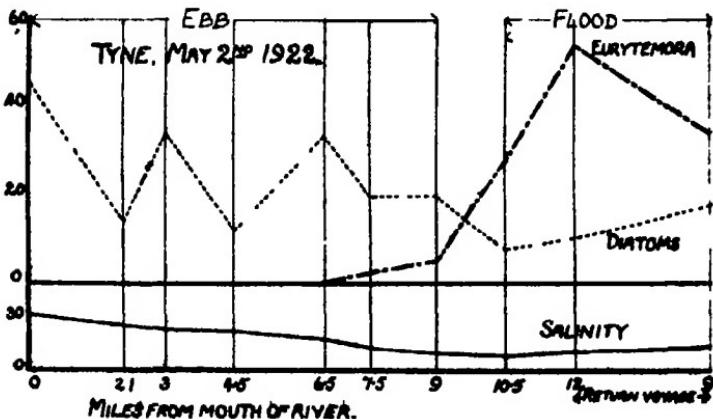
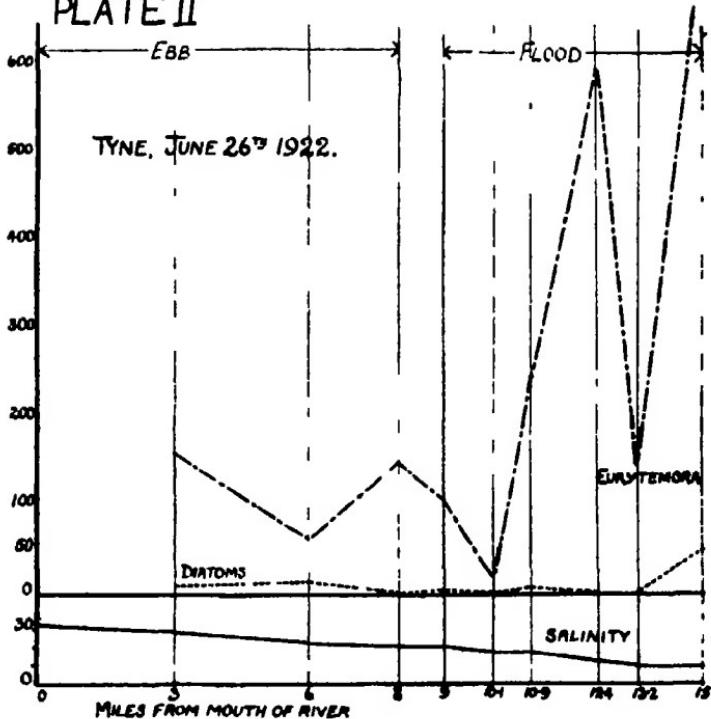
TABLE I

Samples	Marine spp	Estuarine spp	Fresh water spp	Total
Coquet	36	1	1	38
Tyne, May 2nd, 1922	10	2	—	12
Tyne, June 26th, 1922	8	1	—	9
Tyne, July 22nd, 1925	6	2	24	12
Swing Bridge May—Nov. 1925	14 (7 spp occurred only once or twice) 5 spp appeared several times but were always rare)	2	26	22

The Coquet. The samples were taken at fairly regular intervals during a complete tide and with the exception of one estuarine species, *Neomysis vulgaris*, and a single larva of one of the Psychodidae, the contained material proved to consist entirely of marine species of which there were thirty-six. A detailed list of these is given in the above-mentioned report. The number of species and individuals present in the samples varied according to the state of the tide. Temperature can be disregarded as a factor influencing the numbers as it varied only a very small amount—between 11.8 and 12.5 deg. C.—during the experiment.

Each group of organisms was analysed separately and the results, indicated graphically, show a remarkable uniformity in the way in which their numbers vary (See Plate 1). At the end of the ebb tide, when the salinity is lowest, only small numbers of organisms were taken. During the first two hours of the flood tide, while the salinity is rising a slight increase in numbers is observable, but it is not until the maximum salinity (34.20) is reached that a great increase in the numbers present in each group takes place. Just before high tide there is a temporary, but very marked

PLATE II



decrease in numbers and then, when the salinity begins to fall again, a rapid and very considerable increase which is maintained to the end of the experiment—that is three hours after high water, when the salinity has fallen to its original level.

The outstanding fact brought out by this analysis is that large quantities of marine organisms are carried up the estuary at a certain rate by the flood tide and are driven back again during the ebb with increased rapidity due to the fact that the latter is the stronger current, being produced by the combined effect of tide and river.

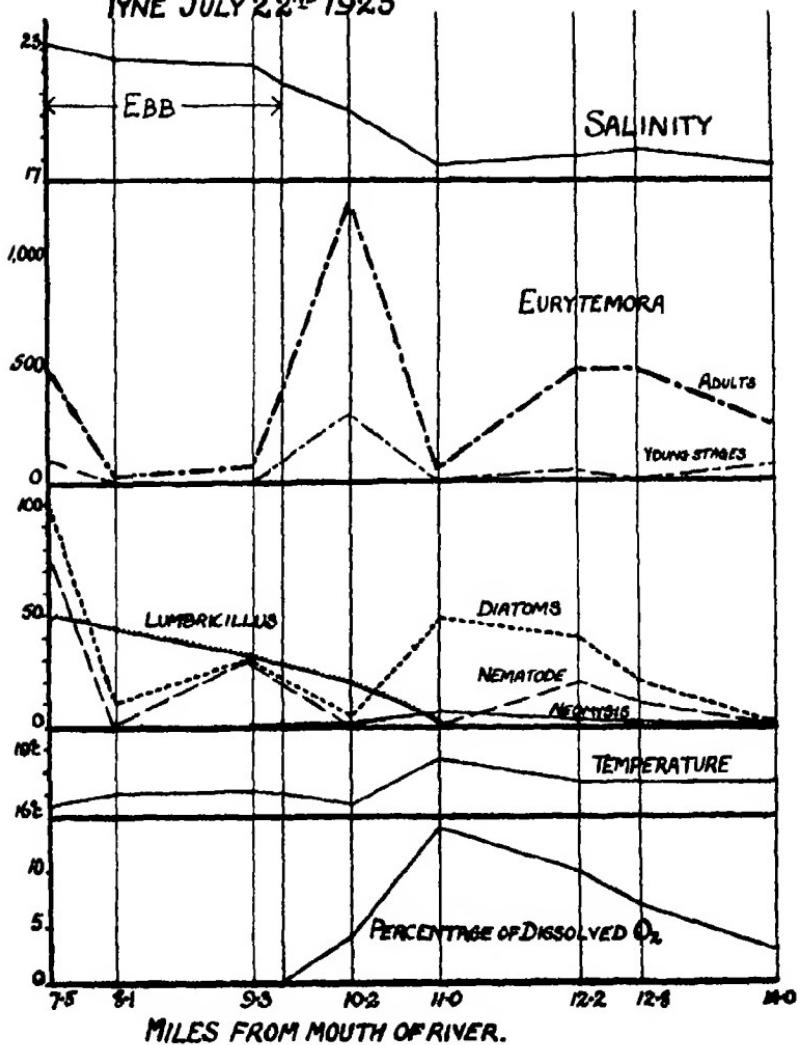
The Tyne, (1922 Samples) As indicated in the tables compiled previously*, the numbers of species and individuals of pelagic organisms obtained in the samples taken in May and July, 1922, were comparatively very small and consisted chiefly of copepods, diatoms and peridinians. It was noted that some specimens of *Neomysis* occurred but that this estuarine form was much less common than elsewhere in the district. The commonest copepod in the Coquet samples was the marine *Temora longicornis*, whereas, in the Tyne samples this was replaced by the closely allied form, *Eurytemora hirundoides*. This species did not occur lower down the river than about three miles from the mouth. Both sets of samples show *Eurytemora* to be particularly abundant near the entrance of the Teams and Derwent into the main stream (Plate II).

Of marine species only phyto planktonic forms, diatoms and peridinians, appear to be able to survive, except on rare occasions, along the whole reach of the long and heavily polluted estuary, and the analysis of the Swing Bridge samples suggests the possibility of some of these being freshwater species carried down from above the tidal area.

July, 1925 On this occasion the sampling began at Felling (Station I), and was continued to a point a short distance above Blaydon (Station 9). The material obtained is more valuable than the previous samples in that we have a record for each station of the amount of dissolved oxygen present, which was abnormally low, and of the temperature, which showed considerable variations both

*Dove Marine Laboratory Report for 1923. For list of species collected in October, 1911, see also Report for 1912, pp. 74-78.

PLATE III.

TYNE JULY 22nd 1925

phenomena are accounted for by an exceptionally hot, dry season and afford an opportunity of studying the effect of these changes in environment on the planktonic organisms concerned.

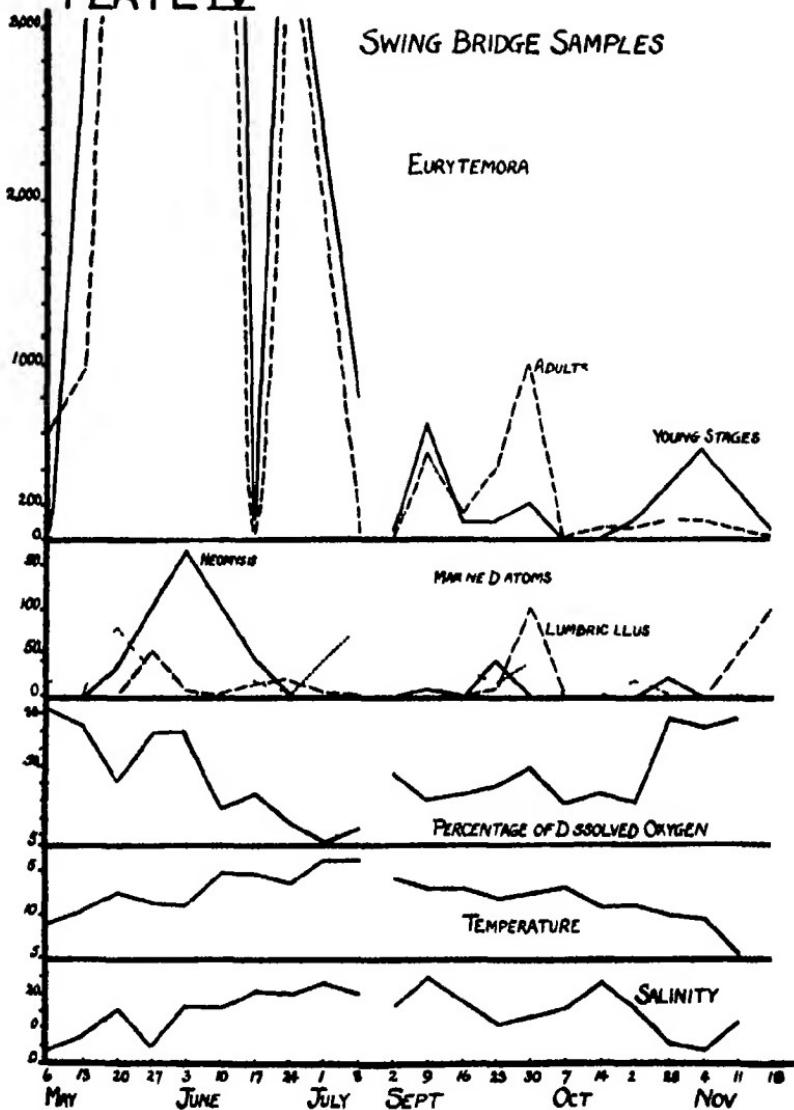
The following table shows the species present and their distribution.

TABLE II

STATION	1	2	3	4	5	6	7	8	9	10
MILES FROM MOUTH OF RIVER	7.5	8.1	13.5	9.6	10.2	11.0	12.2	14.1	12.8	—
Eurytemora (Adults)	700	10	60	—	1200	50	700	700	700	700
(Juv.)	100	—	—	—	300	—	50	60	—	—
Nemachele	80	—	50	—	—	—	70	4	12	—
Lumbricillus	48	30	20	—	—	2	—	—	—	—
Neomysis (Juv.)	—	—	—	—	4	6	4	—	—	2
Water Beetle Larva	—	—	—	—	—	1	—	—	—	—
Psychod Fly Larva	—	—	—	—	—	1	—	—	—	—
Faucheria	48	—	—	—	—	—	—	—	—	6
Vellosira	40	—	10	—	—	—	—	20	—	—
Navicula	—	—	20	—	—	50	20	—	12	—
Other Diatoms	—	10	—	—	6	—	—	—	—	—
Filamentous Alga	—	—	—	—	—	—	—	—	—	—

The graphic representation of the data given on Plate III shows unmistakably that a decrease in the percentage of dissolved oxygen, correlated with an increase in temperature, has a marked effect on the plankton of the region sampled. It is evident that only firmly established estuarine forms are able to withstand the adverse conditions. Eurytemora has tremendous powers of resistance but a very low percentage of oxygen brings down its numbers, especially in the case of the young stages which disappear entirely when the oxygen content falls to zero. The same state of affairs

PLATE IV



obtains in the case of *Neomysis* and it is evident that it is the relatively small quantity of oxygen in the polluted water which is responsible for the comparative rarity of this species in the Tyne

**TYNE ESTUARY
SHOWING
REGION INVESTIGATED**



Swing Bridge Samples Samples were taken weekly from May to December, 1925 except during the greater part of July and August. This omission was unfortunate, as the river was then in a very bad state due to the weather conditions mentioned above, but the effect of this on the plankton has already been seen from the study of the July 22nd material.

The analysis of these samples is given in Table III and is represented graphically on Plate IV.

Eurytemora and Neomysis An examination of Plate IV bears out what has been said as to the relationship between the numbers of these forms and the condition of the water as regards temperature and oxygen-content, this being particularly marked in June and again at the beginning of July, when the temperature rose and the dissolved oxygen dropped below thirty per cent.

The young stages of *Eurytemora* are shown separately from the adults, as otherwise the real differences in number would be still more exaggerated than they must be, as it is, due to the fact that the exceedingly large numbers present in May and June must be accounted for by the reproductive activity of the creatures at that time.

TABLE III

DATE	MAY			JL. NE			JULY			SEPTEMBER			OCTOBER			NOV			DEC				
	6th	1-5th	20th	7th	3rd	10th	17th	34th	8th	2nd	9th	16th	3rd	30th	7th	14th	7th	28th	4th	11th	18th	2nd	9th
Fungicola (1 bluets)	600	1000	6000	8000	12000	—	5000	5	—	500	150	400	1000	—	50	100	100	20	300	—	—	—	—
(Juv.)	100	20000	100000	70000	20000	100000	70000	30	4000	400	100	100	200	—	—	100	300	500	20	100	30	—	—
Acervulus	7-10th	1-5th	30 Jun	100 Jun	1-11th	—	30 Jun	—	—	5 Jul	40 Jul	11	—	—	—	—	—	20 Jul	—	—	—	—	—
Nematodi.	—	—	10	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lambricidae	—	—	50	5	1	10	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Beroe	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pterostichus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sapita	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Carabus Triplex	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Forficula	—	60	10	—	30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chalcoceras Sp.	—	—	rare	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bodilophus Sp.	—	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhinoscielina Sp.	—	—	rare	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Laudana Sp.	—	—	rare	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Coenocladus Sp.	—	—	rare	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Achiatopodus Sp.	—	—	rare	—	rare	—	—	—	—	—	—	rare	—	—	—	—	—	—	—	—	—	—	—
Pleuroxena Sp.	—	—	rare	—	rare	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fresh Water Diatoms (4 spp.)	very	com	mon	—	com	mon	—	—	com	mon	—	com	mon	—	com	mon	—	few	few	—	com	mon	rare
Filamentous Alga	—	com	mon	—	fairly	fairly	com	com	com	com	—	com	com	—	com	com	—	few	few	—	com	mon	few

The smaller numbers of *Eurytemora* and *Nemomysis* from September onwards had the same relation to the temperature and oxygen curves until a considerable fall in temperature occurred in November when numbers of them were evidently killed off by the cold, and the increased amount of oxygen had no apparent effect.

Diatoms Only small fluctuations in the numbers of marine diatoms were noted from May to July, while there was a marked increase in September. The large vernal and smaller autumnal maxima which occur in the numbers of diatoms present in the sea are well known and it is evidently due to the latter that we have greater quantities of marine diatoms in the Tyne at that time, while the experiment was not commenced early enough to show the effect of the vernal maximum.

It was suspected that some few of the diatoms obtained belonged to freshwater species and samples were sent to Dr B M Griffiths at Durham for examination. I am indebted to him for the information that freshwater diatoms are present but that they appear to have been dead or dying when the material was collected. It is apparent therefore, that such freshwater forms are only accidental and temporary sojourners in the estuary and are less resistant to the changed conditions (chiefly as regards salinity, probably,) which obtain in the estuary than are their sea-dwelling relatives.

The freshwater species, considered separately, are seen to be more numerous in May and again in October, suggesting that vernal and autumnal maxima are indicated as occurring among these forms, but rather later than the corresponding phenomena observable in the sea.

Lumbricillus lineatus. One form found in both the Swing Bridge material and the July 22nd samples deserves mention. This is an oligochaete of the family Enchytraeidae, *L. lineatus*, which is not normally planktonic in habit. It is the commonest littoral enchytraeid of northern Britain. It lives under stones, etc. between tide marks and has not been recorded previously from any other type of habitat. I have to acknowledge my indebtedness to Dr J. Stephenson of Edinburgh, for this information and for the con-

siderable amount of trouble which he took in identifying my specimens

The worms were found in considerable numbers between Felling and Redheugh Bridge (Station 5), in July and also occurred in the majority of the Swing Bridge samples from May 20th, onwards. In the July 22nd samples they occupied the region in which the percentage of dissolved oxygen was down to zero, and Professor Meek's suggestion that the presence of the worms in the water was due to lack of oxygen in the mud of the river bed, offers an explanation of what was probably taking place at that time, when the river was in an abnormally bad condition, but it does not account for the state of affairs encountered in the Swing Bridge samples. In these the numbers of worms follow the oxygen curve, being greatest when the oxygen content is high.

We know too little of the condition of the river bed and of the habits of these worms to offer any definite solution of the problem, but it is probable that their presence in the plankton is due, to a great extent, to dredging operations farther up the river. The worms will be disturbed when these are in progress and will be carried along by the stream for some time. That being the case they should make their appearance in greater quantity at the places sampled during ebb tides. An examination of Plates III and IV will show that that is what actually does happen both on the occasion of the July excursion and in the catches made at the Swing Bridge.

Summary From such an examination of the Tyne estuary, from a biological point of view, as is possible with the material under consideration, two facts are outstanding:

1 Far fewer both of individuals and species of marine animals carried up by the tide are able to remain alive for any length of time in the Tyne estuary than is the case in a comparatively unpolluted river like the Coquet. It is only on rare occasions that such forms have been noted from the Swing Bridge, and these only in very small numbers, e.g., a young flounder, a few sagitta, and a ctenophore. (No account is taken of those fishes which during their migrations normally

penetrate more or less successfully in the case of the Tyne, the barrier between fresh and salt water, as they are outside the scope of the present investigation)

2 The only organisms which are able to support life with any measure of success in the Tyne estuary are those which are hardest and most easily adaptable to changes in environment These are represented by —

- (a) The copepod *Eurytemora* which is an estuarine form and extremely hardy It will live for several days in a small tube of Tyne water and is even resistant to small quantities of acid added to the water
- (b) *Neomysis* although adapted to estuarine conditions and common all along the Northumberland coast shows by its comparative rarity in the Tyne, that conditions there fall much below the standard necessary for its successful colonisation of the estuary
- (c) *Lumbricillus* though not normally an estuarine form, has evidently acquired sufficient adaptability to changes in temperature and salinity and to the foul condition of the mud liable to be encountered under stones in the littoral zone to enable it to exist with a considerable amount of success in the lower reaches of the Tyne
- (d) Contributions from fresh water are evidently only accidental and temporary since the freshwater diatoms which are regularly carried down stream in fair quantities appear to be killed off rapidly on reaching the tidal region, and the same applies to a filamentous green alga which occurred fairly commonly in the Swing Bridge samples Aquatic larvæ of insects appeared on only two occasions
- (e) Of marine forms diatoms, and to a much less extent, peridinians are the most persistent in occurrence, as might be expected since they are less dependent than are animal forms on an external supply of oxygen Although they occur with

considerable regularity their numbers are generally small and there is no evidence that they are able to reproduce in the estuary

This being the state of affairs under the best conditions, and these very hardy organisms finding the maintenance of life in the Tyne estuary a very tough proposition, or even entirely impossible during dry, hot weather, particularly in the Felling-Redheugh region, it must be abundantly clear that along the last ten or twelve miles of its course the river is in a very poor way indeed as regards its ability to support living organisms of even the most resistant types

INVESTIGATIONS ON THE LATERAL SENSE ORGANS OF GADUS MERLANGUS

By H C REGNART M Sc

1 The function of the canals and associated sense organs situated upon the body and head of fish has been the source of considerable speculation and research and complete agreement on the subject has not yet been obtained. For example Parker¹ has expressed the opinion that these organs are capable of stimulation by (1) Low frequency vibrations (of the order of about 4 vibrations per second) (2) Pressure

Hofer² on the other hand in a more recent paper stated that these organs were for the purpose of the perception of pressures caused by weak currents and that they were not capable of being stimulated by low frequency vibrations the receptors for the latter being areas of the general integument

The object of this paper is to describe some experiments performed at the Dove Marine Laboratory in which the whiting (*Gadus merlangus*) was subjected to low frequency vibrations over the range 3-30 per sec and to weak currents both before and after section of the nerves to the lateral canals

The investigation was made possible by a grant from the Research fund for the purpose of constructing the apparatus for producing low frequency vibrations and the writer is indebted to Professor Meek Professor Thornton, and Mr Storrow for assistance in planning the work

2 The vibrations were produced with the aid of the apparatus shown in fig 1 A bell shaped iron casting with walls $\frac{1}{2}$ inch thick and a mouth of internal diameter 4 inches was drilled and tapped so that the following additions could be made to it Rubber sheeting $\frac{1}{8}$ inch thick was stretched over the mouth and fixed by means of a wooden collar which was held tightly in position with nuts and bolts The rubber diaphragm was reinforced by two thin steel plates 3 inches in diameter which were tightly clamped together, one on each side of the rubber disc A

piston rod was fixed to the internal face of the compound diaphragm and passed through a stuffing box in the other end of the casting. The end of the piston rod remote from the diaphragm pressed against a cam and a steel spring was arranged to maintain this pressure. The shaft

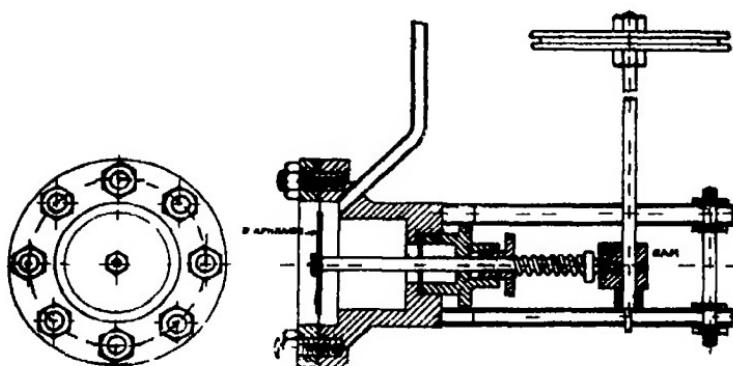


FIGURE 1

of the cam was provided with a six inch pulley. When the pulley was made to rotate it imparted a vibratory motion to the diaphragm by means of the cam and piston. The maximum amplitude of vibrations was $3/16$ inches and the number of revs per sec of the pulley was a direct measure of the frequency of the diaphragm.

The apparatus was rendered water-tight and in addition a long vent-tube was fitted which led from the interior of the apparatus to the air. Thus when the apparatus was lowered into the water, the interior contained air alone, and the diaphragm worked against a water pressure on one face only. The axle of the pulley was made sufficiently long to project well above the water and the pulley lay in the horizontal plane.

A special tank was then constructed the external dimensions of which were 12 ft long, 17 ins wide and 14 ins deep. The sides were 2 inches thick.

The apparatus was submerged in water at one end of this tank and rested on rubber pads to avoid the transmission of vibrations by any other means than by the

diaphragm. The pulley was driven by belting from a set of cone gears which were set in motion by a 2 h p electric motor. The apparatus was arranged so that frequencies over the entire range 3-30 could be produced when required. These frequencies were checked by measuring the speed of rotation of the pulley by means of a direct reading tachometer.

A large number of whiting whose average length was 1 ft were maintained in tanks and the floor pool, and they were transferred to the experimental tank when required. When this was done they were always left for three or four hours to become accustomed to their new surroundings. Normally the fish swim freely about the tank and only when unhealthy or damaged lie on the bottom or remain in corners.

The lateral canals in the whiting are on each side (after Cole') the (1) Supra orbital canal, (2) Infra orbital canal, (3) Hyo mandibular canal, (4) Lateralis canal and the corresponding nerves which supply them are the (1) Superficial ophthalmic trunk of the facial nerve, (2) Infra orbital trunk of the facial nerve, (3) Hyo mandibular trunk of the facial nerve and (4) lateralis trunk which divides into the dorsal and ventral rami.

The superior ophthalmic branch of the trigeminal nerve is closely associated with the superficial ophthalmic trunk of the facial nerve and section of the nerve to the supra orbital canal involves cutting also the nerve which supplies the skin of the anterior part of the head.

The relations of the distribution of these nerves with the external features of the fish were worked out so that any or all of these nerves could be cut in healthy fish for experimental purposes. This operation was performed with a very fine needle knife. The fish were then put back into the tanks and left for several days to recover.

The operation results in a certain lack of muscular vigour and this is probably related to the association of these nerves with the acustico lateral centre which is partly connected with the maintenance of muscular tone. In the subsequent experiments only those fish which had fully recovered (with the exception of the slight loss of vigour)

were used. When this was the case they swam about like normal fish though not so rapidly. At the termination of the experiments the fish were killed and after hardening in spirit dissected to verify the nerve cutting work.

(3) The conduct of normal fish was first observed. Their behaviour consists in swimming freely about the tank. When the diaphragm was made to vibrate over the frequency range 3-30 an immediate response was obtained. If within 2 or 3 ft. of the apparatus the fish rapidly retreated for several feet, then turned and remained facing the diaphragm (i.e. the head and long axis of the body pointing towards the diaphragm) at the same time vigorously moving the pectoral fins and giving slight undulating movements of the body and dorsal fins.

After this movement of orientation which appeared to be for the purpose of locating the exact source of disturbance the fish usually swam round in one or more circles, finally swimming to the opposite end of the tank. If the fish was more than three or four feet away from the diaphragm when the vibrations were started it immediately gave signs of stimulation consisting of cessation of swimming in the original direction and placing itself in a position so as to face the source of disturbance. Thus if swimming away from the source it would at once swim round so that the head pointed in the direction from which the vibrations came at the same time moving the fins in the manner described. Very often the fish in this position would move slowly backwards with the aid of the pectoral fins. This series of movements was nearly always followed by a retreat of the fish to the other end of the tank. If swimming towards the source of disturbance, starting the vibration caused the fish to cease swimming forward and proceed as in the last case. Sometimes after the movements of apparently locating the source, the fish would swim one or two feet forward, but a retreat always followed. Frequently vigorous biting and more vigorous opercular movements were observed on stimulation.

When the frequencies were higher than about 10 the responses though definite were not so vigorous. The responses also soon ceased if the experiments were performed

too frequently and tests were usually made at intervals of $\frac{1}{2}$ to $\frac{1}{4}$ hour

Fish which had gone blind in the tanks but were otherwise healthy, were found to respond more vigorously to these stimuli and did not learn to ignore them so quickly

The next experiments consisted in cutting the nerves to all the lateral sense organs in six fish. Four recovered and on being subjected to vibrations over the range of 30 gave definite evidence of stimulation. The movements however, differed from those observed in the case of normal fish. No temporary movements of orientation were made, and there was frequently simply circular swimming. When within two or three feet of the source the fish retreated to the other end of the tank.

In another set of experiments seven fish with all the lateral organs eliminated were used. The same results were obtained as before, namely a retreat from the source if near fin movements but no movements of orientation towards the source.

In two fish the nerves to the lateral line sense organs on both sides of the body were cut and those to the sense organs of the head left intact. In this case the fish which had been operated upon behaved generally like a normal one except that the movements of orientation were slow and performed apparently with difficulty.

Next the supra-ophthalmic nerves of two fish were cut on both sides, thus eliminating the supra-orbital canals and the skin of the anterior part of the head. The fish were stimulated by the vibrations but the movements of orientation were severely impaired and in most cases were not definitely recognised as such.

Finally in two fish all lateral sense organs were eliminated on both sides except those of the supra-orbital canals. The fish were stimulated as before but no movements of orientation were made.

In another set of experiments a weak current of water was used. A glass tube connected with the siphon of a large tank of water was placed horizontally in the tank, and by placing threads in the tank was found to produce a current, the influence of which extended for a distance of

about two feet. Normal fish on swimming near the mouth of the tube performed the movements of orientation described above. Fish in which all the lateral sense organs had been eliminated gave evidence of stimulation but did not give the movements of orientation.

I have to thank Professor A. Meek for the fish used for experiment and for granting me facilities at the Dove Marine Laboratory.

SUMMARY

1. *Gasterosteus aculeatus* was found to be capable of the perception of vibrations over the frequency range 3-30 (vibr. per sec.)

2. The lateral canals and skin of anterior parts of the head are not essential for the perception of these vibrations.

3. Normal fish perform movements which appear to be associated with the location of the source of the disturbance.

4. Elimination of the lateral sense organs results in the loss of this ability of the fish to orientate it body in relation to the source of disturbance.

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THE PROJECTED CHEMICAL SENSE IN THE COELENTERATA AND CHINODERMATA

By H C REGART M Sc

Reactions to food at a short distance by *Actinians* have been described by Pollock who experimented with anemones left in pools by the receding tide and found that they generally gave reactions by expanding when pieces of mussel limpet etc were placed near them on the floor of the pool. He found that the greatest distance at which the food could cause this effect was about 9 inches and he showed that sunlight was not the cause of the expansions by making tests in shaded pools.

Jourdon in 1891 (*Die sinne und Sinnesorgane der niederen Thiere*) expressed the opinion that these results were manifestations of a taste sense in *Actinians*. Loeb¹ 1891 after performing experiments on several different genera namely *Adamsia*, *Actinia* and *Anemonia* found a sense of taste in the tentacles and disc. Nagel² 1892 using *Adamsia* and *Anemonia* found a taste sense only in the tentacles and not in the disc. Results similar to those of Pollock were obtained by Parker³ 1896 who put specimens of *Metridium* in separate vessels of sea water and observed that a small amount of mussel juice put into one of the vessels caused most of the individuals to expand while those in a vessel without mussel juice remained closed. He did not find however that the tentacles were noticeably affected by food dissolved in the water. Fleuret and Walton⁴ 1907 found that the tentacles of *Actinia* and *Tentaria* were almost completely indifferent to chemical stimuli that they were likely to meet with under normal conditions.

PART I

The object of this paper is to describe experiments made to ascertain whether (1) *Tentaria crassicornis* is capable of being stimulated by food at a distance, (2) the disc is more chemically sensitive than the tentacles.

It was found that *Tentaria crassicornis* reacted to food

(mussel, limpet, etc.) lying near them on the floor of the tank by expanding, and if the food were sufficiently near, they made attempts to obtain it. The anemones made movements to obtain the food only if it were comparatively near (within 7 inches) and at greater distances tended to make random movements. A few drops of mussel juice placed in a large tank caused many individuals to expand.

A typical experiment is shown in the photographs of Fig 1. A rock to which four anemones were attached was placed in a convenient tank and left for two days so that the anemones might recover from the shock of removal. The anemones were large varieties of *Tealia crassicornis* (about four inches diameter when fully expanded) from deep water and an *Actinoloba*. At the initial stage of the experiment one had become almost fully expanded while the others remained closed. A small piece of herring about 1 inch square by $\frac{1}{2}$ inch thick was hung three inches from the tentacles and to one side of the expanded anemone (the apparent large size of the food as it appears in the photographs is due to the effect of the temporary lighting). The experiment was started at 1 o'clock. Ten minutes later a few tentacles were pointing stiffly towards the bait. Occasional convulsive movements of the tentacles and disc also occurred on the side nearest the food. The photographs which were taken at intervals of an hour until 4 o'clock show a gradual movement towards the food and also show that the other individuals have also been stimulated to expand and move slightly towards the food.

At 4 o'clock the food had not been reached and the experiment was left in progress until the following morning. The next day at 9 a.m. the food had been reached.

The next experiments were made to ascertain whether the tentacles or the disc were the more chemically sensitive to dissolved food material. This was done by testing one tentacle at a time in different individuals so that there was no cumulative effect produced. For example ten anemones were put into separate vessels of sea water. Then a single tentacle was tested in one anemone after the other. In the first set of experiments small pieces of limpet were held close to but not touching the tentacles. Out of 120 such

tests only 6 tentacles gave any kind of response, 3 of them waving about vaguely and 3 suddenly contracting. Large pieces of juicy food affected the tentacles, but small quantities produced no response. The tentacles could not be said to have a distance chemical sense.

A pipette was made so that solutions could be slowly discharged so as to bathe the tentacles. About 4 cc. was allowed to flow out at a time and the nozzle was 6 mm wide. It was found that allowing pure sea water to diffuse slowly round the tentacles produced no effect. Dilute food solutions were tried next. These were made approximately the same strength by chopping up a given small amount of mussel each time in a large volume of water and filtering the mixture. Discharging the solution a short distance from the tentacles would render it still more dilute. For this experiment 50 individuals of *Tealia crassicornis* were put in tanks and allowed to become accustomed to the change. When they had expanded one tentacle was tested at a time as before. 1,000 tests were made and allowing for a few doubtful ones the approximate responses were between 6% and 10%. This result indicates that the sensibility of the tentacles to dissolved food must be small.

Finally experiments were made to test the sensitivity of the disc to the same kind of solution. Food solution was allowed to diffuse over the disc by holding a pipette over it in such a manner that the level of the food solution in the pipette was the same as that of the water outside. When it was required to diffuse the solution over the disc the pipette was slowly raised.

In nearly all cases there was a slight but perfectly definite response. This took the form of a bristling or stiffening of the tentacles probably caused by the movements of the disc. Repeated tests caused the tentacles to slant inwards over the disc. 500 tests were made and the responses reached about 90%. These responses were taken to be due to chemical stimulation because —

- (1) The bristling movements always took place a few seconds after discharge of food material upon the disc, whereas when movements due to shock took place, a very short interval elapsed between stimulus and response.

(2) These movements were not obtained if pure sea water was used

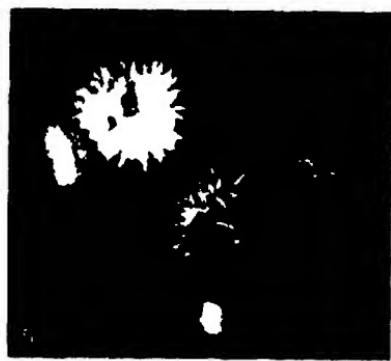
PART II

The common star fish *Asterias rubens* was found by Romanes¹ 1880 to have an olfactory sense distributed over the surface of the tube feet but most highly developed in those tube feet at the end of the arms. These terminal tube feet are not used for progression but wave slowly about in the water and undoubtedly act in a sensory capacity. The experiments to be described were made for the purpose of ascertaining whether *Asterias rubens* could find food hidden at a distance.

In the first experiments small pieces of mussel were hidden among a pile of glass jars. *Asterias rubens* was found easily to obtain the food provided the water was well aerated. Poor aeration prevented movements for seeking food being made. The problems provided were often of considerable difficulty but the starfish succeeded in obtaining the food. Progressive removal of the tube feet led to a diminution in the power of obtaining food.

Two exactly similar maze tanks were constructed (A and B fig 2). One tank B contained food suspended in a bait chamber C at one end and the other A contained no food and was simply used as a control. The starfish had frequently been found to tend to move to the places of best aeration. To avoid this the aeration pipes were placed in the centre of each maze and the starfish at the beginning of each experiment put there also. Thus when the starfish moved they had to leave the position of best aeration in order to obtain food.

Starfish were found to be capable of easily finding the food when present moving from the centre of the maze to the bait chamber while the starfish in the foodless chamber used as a control remained near their original position. The photograph shows a typical experiment. After removal of the tube feet the movements towards the food were not so definite and were also very slow. Removal of the

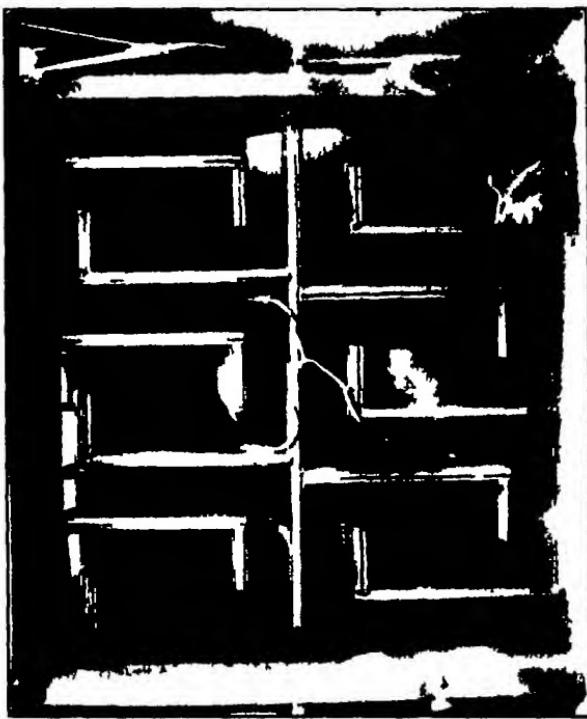


FIGURE

A

B

C



FIGURE

terminal tentacles did not affect the capacity for locating the food. In these experiments both *Asterias rubens* and *Solaster papposus* were used.

SUMMARY

1 *Tealia crassicornis* was found to react to dissolved food material, and if food were sufficiently near, movements were made to obtain it.

2 The disc was found to be highly sensitive to dissolved food material, the tentacles relatively insensitive.

3 *Asterias rubens* and *Solaster papposus* were found to have the capacity to find hidden food by a projected chemical sense, which was located on the surface of the tube feet but mainly in the tube feet near the ends of the arms.

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- ⁵ Romanes, 1885 Jellyfish, starfish and sea urchins

A PRECISION ELECTROSCOPE

By L. BASTINGS, M.Sc., B.A.

Comparative measurements of the activity of radioactive sources, as usually carried out by the aid of a gold leaf electroscope of simple design cannot be regarded as of a high order of precision. Various workers have claimed an accuracy of one in two or three hundred under favourable conditions. But greater accuracy than this is desirable in many radioactive problems, and no doubt soon will be demanded also in the standardisation of supplies of radium for scientific and commercial purposes.

In the usual method of measurement with an electroscope, the image of the gold leaf is superimposed on a scale in the eyepiece of the observing telescope, and its movement timed by eye and stop watch. An obvious improvement on this lies in the direction of recording the movement automatically. This may conveniently be achieved by illuminating the leaf with an intense source of light, and projecting an image of it, together with suitable distance and time marks, on to a photographic film moving in a direction at right angles to that in which the leaf moves. The following details of this method have been tried with some success.

The end of the leaf is provided with a fine pointer of quartz fibre, about 0.05 mm. in diameter, and a couple of mm. in length. A small piece of fine quartz rod is heated momentarily in the oxy-gas flame, and allowed to draw itself out gradually under gravity until it becomes detached. The thick end of this fibre now acts as a handle by the aid of which the fine tip may be attached to the gold leaf with a trace of shellac varnish. The pointer is then cut off to the desired length by a sharp razor, and the leaf freed by means of a slip of grease-free paper.

The electroscope case in which the leaf is enclosed is provided with two windows, one of which is of optically plane glass. Light from a source of considerable intensity, such as a "Pointolite," is passed through a heat-absorbing cell, and concentrated by an achromatic condensing lens so

as to cast an image of the source of light in the same plane as that in which the pointer moves. The beam emerging from the case of the instrument is projected by a microscope (a 40 mm apochromatic object glass of 16 N A, together with a compensating eyepiece, $\times 8$, were used) on to the cylindrical lens of a paper camera by the Cambridge Instrument Co. In this apparatus, a roll of bromide paper, 6 cm wide, is driven past the focal plane of the lens by a motor and speed reducing gear, steadied by a fly wheel. Etched lines on the face of the lens cast upon the paper shadows which act as distance marks, while at right angles to these a time scale is imposed by intercepting the beam periodically with the sectored wheel of a phonic motor actuated by a tuning fork.

On development, the photographic paper reveals, running diagonally across the time and distance marks, a fine linear trace of the leaf movement which may be measured up and interpreted at leisure. By running the paper at suitable speeds (from 10 cm to 1 metre per minute) rates of discharge of the electroscope of from 4 to 36 volts per minute have been successfully recorded with this apparatus. And throughout, a consistency of the order of 1 in 1,000 has been maintained.

With discharges of the electroscope at the slower rates, another possible source of inaccuracy become prominent, due to fluctuations in the natural leak of the instrument. Apart from unavoidable external sources of ionisation, such as the general radioactivity of the earth and air, and the penetrating "cosmic radiation," the natural leak is due mainly to alpha-ray activity in the materials of the instrument. Fluctuations in the ionisation from this cause may amount to as much as 10 per cent of the natural leak. If then the natural leak accounts for more than 1 per cent of the total ionisation, this unreliability in the natural leak may be responsible for inconsistencies in the measurements within the limits of experimental error due to other causes. It is not an easy matter to obtain a natural leak as low as 0.1 volt per minute in an electroscope of the usual dimensions. Materials of low atomic number are in general more suitable in this respect, in so far as they are usually

less radioactive (Aluminium and brass are most commonly employed for electroscope cases) On the other hand, materials of high density are more suitable for the case of a gamma ray instrument because of the more intense secondary ionisation which such materials emit under gamma ray irradiation After some searching, it was found that the best ends could be served by the use of old lead, the radioactivity of the short lived products in which had decayed since separation from the parent ore Some old lead, removed from the roof of Durham Cathedral during repairs, and believed to be at least 400 years old, was made up into an electroscope, and gave results of a much more satisfactory character than had been produced with any previous instrument

While maintaining an unusually high sensitivity, this electroscope had a natural leak of less than 0.1 volt per minute Where the thickness of the lead wall is a disadvantage, the lead may be made into a solder with a little tin, and applied with a flux to the interior of a brass case heated to the appropriate temperature Such a device proved invaluable when an airtight instrument of relatively high sensitivity was required

A number of other minor innovations have also been introduced for enhanced accuracy, or for the purpose of dealing with weak radioactive sources Further details of these and kindred matters will be found in a paper entitled 'Precision methods in Radioactivity,' in the Journal of Scientific Instruments, Vol V, No 4, April, 1928, p 113

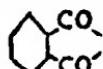
PROPERTIES AND REACTIONS OF SOME
TOUENE SULPHONIC ESTERS

(An Abstract of a paper published in J C S 1928 723)

By G R CIEMO D Sc D Phil and
L WATSON M Sc

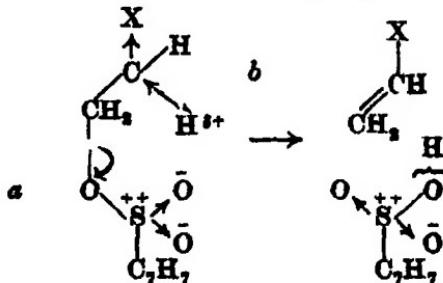
β Chloroethyl and β cyanoethyl toluene p sulphonates $C_6H_5SO_3CH_2CH_2Cl$ and $C_6H_5SO_3CH_2CH_2CN$ are prepared by condensing toluene p sulphonyl chloride with ethylene chlorohydrin and ethylene cyanohydrin respectively. By treating the β cyanoethyl ester with ethyl alcoholic hydrogen chloride and hydrolysing the crystalline product the hydrochloride of iminoethoxypropyl toluene p sulphonate $C_6H_5SO_3(H)CH_2C(OH_2)CH_2NH_2HCl$ with water β carbethoxyethyl toluene p sulphonate $C_6H_5SO_3(H)CH_2CH_2COOC_2H_5$ is obtained.

These esters show very contrasting properties under alkaline conditions. Whereas the β chloroethyl ester is comparatively stable to treatment with caustic soda solution, the β cyanoethyl and β carbethoxyethyl esters hydrolyse with ease to give toluene p sulphonic acid and acrylonitrile $C_6H_5CH_2CH_2CN$ and ethyl acrylate $C_6H_5CH_2CH_2COOC_2H_5$ respectively. Thus acrylonitrile and ethyl acrylate may be prepared in good yield by heating the respective esters with potassium carbonate. The same behaviour is shown when the three esters are treated with potassium phthalimide.

Phthal β -chloroethylimide  is produced

in the case of the chloroethyl ester but hydrolysis occurs in the other two cases. Again the β chloroethyl ester reacts smoothly with phenyl magnesium bromide to give β chloroethylbenzene $C_6H_5CH_2CH_2Cl$ but the other two react violently, with production of complex mixtures.

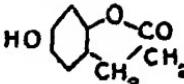
A satisfactory explanation of this difference in chemical properties, from the electronic point of view may be reached by a consideration of the following representation.



in which X represents either the cyano- or the carbethoxy-group

On the other hand the reactions of these esters under acid conditions proceed without hydrolysis, and shew definite similarities β chloroethyl, β cyanoethyl, and β carbethoxyethyl toluene p sulphonates condense with benzene in the presence of aluminium chloride to give dibenzyl, $C_6H_5CH_2CH_2C_6H_5$, phenylpropionitrile, $C_6H_5CH_2CH(CN)CH_2$, and ethyl phenylpropionate $C_6H_5CH_2CH_2COOC_2H_5$, respectively in good yields. This modification of the Friedel Crafts reaction appears capable of considerable extension.

Finally it may be mentioned that the β cyanoethyl ester reacts with resorcinol in the presence of zinc chloride and dry hydrogen chloride to give 7-hydroxy-4

dihydrocoumarin HO  The production of

this compound constitutes one of the few exceptions to the important and widely used Hoesch reaction

A COMPARISON OF PALAEozoic MOUNTAIN CHAINS IN EUROPE AND NORTH AMERICA

By E B BAILEY, M C , Lég d' Hon , B A , F R S E , F G S

The North American continent is, broadly speaking, a magnified mirror image of much of Europe. North America has three major divisions (1) an Atlantic border of Palaeozoic mountains (Appalachian System), (2) an immense central region (Laurentia of Suess) that has suffered no mountain-making deformation since the dawn of the Cambrian, and (3) a Pacific Cordillera (Rocky Mountains, etc) characterised by Mesozoic and Tertiary compression. Both the Atlantic and Pacific mountains have been folded and thrust over the margins of the intervening stable element. In Europe we find (1) a Palaeozoic border chain that runs through Scandinavia and Britain, (2) a central region that we may christen Baltica, a region of Cambrian and post Cambrian tranquility, and (3) a Mesozoic Tertiary cordillera (Carpathians, Crimea, Caucasus). Here again the mountain elements (1) and (3) are folded and thrust upon the margins of the buffer state (2). The Baltic Shield matches the Canadian Shield, and the Russian Platform extending through Denmark into East Anglia serves as the counterpart of the Great Plains of North America. The pivot of this comparison is furnished by the Caledonian Mountain Chain of Scandinavia, which has its western equivalent in the ancient mountains of Newfoundland and Nova Scotia. In the Appalachian System the important tectonic feature is the crossing of the Caledonian Mountains by the Hercynian, which in South Wales and Ireland are in contact, while to the east they separate, the former being traced north-east into Lapland, the latter due east into Poland. The geological structures on the two sides of the Atlantic are thus apparently complementary and lend support to the idea of some type of continental drift.

PAPERS READ BEFORE THE SOCIETY DURING
THE SESSION 1927-28

- 1927**
- Nov 17th— The Post Glacial Drainage System around Lintrathen
By Dr D A Allan
- 17th— Coal Ash By Dr J C Kellett
- Nov 24th An Experiment on the Torsional Vibrations of an Engine Shaft By Dr C R Goldsborough and Dr H Baker
- Dec 1st The Application of Physics to Agriculture from the 16th Century to the present day By Dr B A Keen
- 1928**
- Jan 28th Memories of Greece 1897-1917 By Mr R C Bosanquet
- Feb 4th— On the Replacement of Species by others of similar habit By Mr J Orr Cooper Dr B M Griffiths and Professor H J Hutchens
- 16th The Band Spectrum of Helium By Professor W E Curtis
- 16th— Some Reactions of Sulphonic Esters By Mr E Walton
- Feb 22nd— Across Canada with Princeton University By Mr I B Bailey
- Mar 6th Chromosome shape in *Lichenalia* and *Puschkinia*
By Miss F M Greeves
- , 6th A note on Natural Selections in the Praying Mantis By Professor J W H Harrison
- 8th— The distribution of the Mussel bands of the Northumberland and Durham Coalfield By Dr W Hopkins
- 8th Recent Developments in Practical Plant Feeding By Professor C Heigham
- April 24th— Accurate Radioactive Measurements By Mr L Basting
- May 1st— Inequalities from a Geometrical Point of View By Mr J L Burchall
- , 1st— Transformation Formulas in Infinite Series By Dr F H Jackson

COMPLETE LIST OF THESES ACCEPTED FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
OF THE UNIVERSITY OF DURHAM

<i>Year</i>	<i>Candidate</i>	<i>Title of thesis</i>
*1922	McLelland E W (<i>Arms</i>)	Condensations of Ortho thiol benzoic Acid
1923	Smith C A (<i>Arms</i>)	Economic Antinomies a study in Economic Psychology
1924	Farr C (<i>Arms</i>)	The contributions to English Philosophy by XVIIIth century leaders of religion with special reference to John Wesley
1924	Hanson P G (<i>Arms</i>)	The Stoic View of Life
1924	Sedgwick W C (<i>Arms</i>)	Part I Conversion of lactose to a hexose pentose Part II Selective methylation of glucose Part III Some derivatives of tetrahydroacridone and tetrahydroacridine
1924	Clark W J (<i>Arms</i>)	A new method of determining Ionizing and Radiating Potentials of Gases not necessitating low pressure
1924	Felfer L V (<i>Arms</i>)	The Resistance of Vessels
1924	Ruell D A (<i>Arms</i>)	Part I Constitution of raffinose and in ribose Part II The ring structure of galactose
1924	Linnell W H (<i>Arms</i>)	Part I The Constitution of Cane Sugar Part II Tetramethyl γ fructose Part III 2 : 6-Tetramethyl glucosid Part IV Derivatives of Acridone and Tetrahydro carbazole Synthesis of Amygdalin and related compounds
1925	Campbell R (<i>Arms</i>)	The constitution of Amygdalin
1925	Wylam, B (<i>Arms</i>)	(a) The constitution of Gentio biose and its identity with the biose of Amygdalin (b) The constitution of Gentio nose
1925	Baker, S (<i>Arms</i>)	Part I A study of the Acetals of Glucose Part II 'The Synthesis of derivatives of Arabinose'

*This year stated is that in which the degree was conferred

<i>Year</i>	<i>Candidate</i>	<i>Title of thesis</i>
1925	Westgarth C C (Arms)	Part I The Amylene Oxide form of Galactose Part II Synthesis of derivatives of γ -Xlose Part III The structure of Isomaltose Part IV Preparation and study of Carbonic Ester derivatives of Sugar
1925	Maw W (Arm)	Part I Carbonates of Ethyl and Glycol and related substances Part II Carbonates of the Pentoses
1925	Slyce T A (Arm)	Part I The development of a new method for measuring Specific Inductive Capacity Part II The effect of intensive drying upon the dielectric constant of Benzene Part III The Critical Phenomena of Air Discharge Tubes under conditions of continuous flashing
1925	Taylor J (Arms)	The intermittent electrical discharge in gases
1926	Stephenson G I (Arms)	Part I A determination of the atomic weight of Boron and a comparison of the densities of Boric Oxide from various sources Part II The chemical effects of heavy electrical discharges in Tungsten wires and of high tension electrical discharges in Mercury vapour Part III A determination of the melting and transition points of Potassium Dichromate and a thermal investigation of the Potassium Acid Sulphates
1926	Hopkins, W (Arms)	'A further correlation of the Coal Seams of the Durham Coalfield'
1926	Orr, W B (Haff)	"The Reactivity of Aliphatic Nitro compounds and derivatives of 1-8-Diketones"
1927	Rose, T H (Arms)	'Reaction and 'lime requirement' in relation to the fertility of soils in the northern provinces'"

<i>Year</i>	<i>Candidate</i>	<i>Title of thesis</i>
1927	Smith H C (Arm.)	A comparison of the atomic weights of Silicon and Boron from different sources The hydrolytic action of low pressure superheated steam on salts of the alkaline earth metals
1927	Crawford A (Arm.)	Part I Methyluron and constitution of Mannitol Formation of Pentamethyl Mannose of the true Aldose type Part II Constitution of the Stable Dextrin from Starch
1927	Aberlom R G (Arms)	(1) Coal balls from a new horizon and locality in Northumbria (2) On a specimen of Calamopitys (Eustophylon) beinerianum showing annual rings (3) The geological relations of the coast sections between Lynemouth and Seaton Sluice
1927	Hodge M B (Arm.)	The Permian Sands and Marl Shale of the North East of England
1927	Lloyd W (Arm.)	Molecular Activation
1928	Clarkson W (Arms)	On Electrical Discharges, Static and Dynamic
1928	Kellett J G (Arms)	The Organic and Inorganic Constituents of Bituminous Coal Seams
1928	Peele J B (Arms)	Some Compounds of Selenium
1928	Smith J M (Arms)	Part I Studies in the Nitration of Phenyl Aromatic Amines Part II Reduction of Dimethoxy succinic Anhydride Part III Experiments upon Phthalic Dialdehyde

LIST OF PAPERS PUBLISHED FROM THE
LABORATORIES OF THE UNIVERSITY OF DURHAM
during the Session 1926-1927

- Absalom, R G. Recent Palaeontological Discoveries in Northumberland, *Proc Univ Durh Phil Soc*
- Allan, D A. The Geology of the Highland Border from Layside to Noranside, *Irish Roy Soc Idin*
- Allan, D A. "The Stratigraphy of the British Carboniferous," *Compte Rendue du Congre international de*
- Allpress, C F., Haworth, W N. and Inkster, J J. Sugar Carbonates. Derivatives of Methylfructoside, Ethylfructoside and Normal Methylfructoside, *Journ Chem Soc*
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THE LOWER CARBONIFEROUS COAL-BALL FLORA OF HALTWHISTLE, NORTHUMBERLAND.

By R. G. ABSALOM, M.Sc., Ph.D., Keeper of Geology,
The Museums, Liverpool.

1. *Introduction.* This paper seeks to set forth the palæobotanical results of research work carried out on one of the coal seams present in the calcareous beds of the Lower Carboniferous Series of South-West Northumberland. The work was undertaken with the object of proving the existence of a new geological horizon and locality for the plant-bearing nodules known as coal-balls and of effecting a comparison of the contained flora with that of the coal-balls previously described from other horizons and localities in Britain.

As the stratigraphical details are being reserved for a separate account it is only necessary here to give the broadest outline with regard to the horizon.

2. *Horizon of the material.* Coal-balls with the plant structure fairly well preserved were found, and the material examined thus constitutes the first record of their occurrence in Northumberland. The horizon is the Little Limestone Coal of the Bernician Series of the Lower Carboniferous; the locality the South Tyne Colliery, Haltwhistle, Northumberland.

The horizon and locality are both of great interest in that they are situated, both geologically and geographically between the previously recorded occurrences of coal-balls and similar plant-bearing material in Great Britain. The Pettycur, Fife, material is from a horizon low down in the Calciferous Sandstone Series, i.e., practically the base of the Lower Carboniferous Series, whilst the new horizon is situated in the topmost limestones of that series. The Lancashire and Yorkshire Coalfield horizons are well up in the Lower Coal Measures so that the new horizon is distinctly nearer to the Pettycur deposits from the point of geological age.

In view of this intermediate position it is of interest to note whether or not the contained flora shows any indications of the onset of the flora characteristic of the Lower Coal Measure deposits, i.e., if the flora was in a transitional stage between Lower and Upper Carboniferous forms.

3. Description of Species comprising Flora.

Stauropteris burntislandica, P. Bertrand, and *S. oldhamia*, Binney. Pl. 1. Fig. 1. The petioles have a rectangular stele with four groups of primary xylem arranged in the characteristic cruciform manner. They are tetrach with the protoxylem situated crescentically around the poles of the wood, save in one petiole in which there are two protoxylem groups at each angle, some of the tracheides having begun to move outwards through the cortical zone as leaf-traces. The tracheides of the primary xylem are mainly of the scalariform type, a few of the protoxylem tracheides exhibiting true spirals.

The stele is surrounded by a mass of thin-walled phloem cells which fill the bays of the xylem and, in a few cases, extend to the centre, displacing the wood. The phloem cells are often elongated in directions parallel to the sides of the stele and sieve tubes are common among the phloem in the bays of the wood. The pericyclic zone is usually ill-defined, the phloem passing rapidly into inner cortex consisting of fairly thick-walled parenchymatous cells, some of which are filled with a brown resinous substance. The outer layers of the cortex are formed of smaller cells which assume a radial arrangement and are replaced in the hypodermal region by thin-walled palisade tissue. The epidermis is composed of a single layer of square cells with black thick walls.

The petioles are surrounded by numerous branchlets of various orders showing both quadrifid and trifid axes and single vascular strands. Two steles are present connected by a strip of cortical tissue, and are approximately equal in size, pointing to dichotomous branching. Out-growths at the free ends, in which the vascular axes, though perfectly circular, are still quadrate in internal structure, are probably secondary branchlets.

Scattered throughout the material are many dehiscent sporangia, they are pear shaped organs with an outer wall consisting of a single layer of thick walled cells. There is an inner layer or tapetum two or three cells deep in which the cells are parallel to the outer wall. The cells grow progressively smaller towards the tip of the sporangia where the rupture has taken place. There is no sign of a pedicle.

Bensonites fusiformis R Scott (Pl I Fig 2)¹²²⁴ Many examples of this peculiar organ are found intermingled with sections of *Stauropteris*. The structure is divisible into three definite sections, the pedicle, the body and the head or beak. The head is sharply differentiated from the body and terminates in a sheath or beak like process. It contains either a single or a double hour-glass shaped structure which always appears to be composed of a reddish-brown membranous material. The body is a rather cylindrical object tapering at the base into a pedicle and consists of delicate, regular, spherical cells, extremely loosely packed, enclosed in a very thin epidermal layer. A single vascular strand of very small elements spirally reticulated, traverses the pedicle and appears to terminate suddenly among the loose spheres in the body.

In one section the organ appears to originate as a lateral outgrowth of a rachis of *Stauropteris*, while another extremely small specimen lies buried in a mass of feathery tentacles at the apex of a rachis which also has a glandular opening of the *Lyginopteris* type halfway down one side.

Heterangium Grieves, W C Williamson (Pl I Fig 3)⁵⁶⁷⁸⁸ This plant is represented by sections of half a stem cut in an obliquely transverse direction, the complete stem having had a diameter of approximately one centimetre.

The Stele. The central cylinder consists of groups of large tracheides interspersed with anastomosing bands of small-celled conjunctive parenchyma. No pith is present, the largest tracheides being in the centre with the smaller tracheides of the protoxylem grouped into xylem strands at the periphery. The tracheides of

the metaxylem bear multiseriate bordered pits while the protoxylem elements are spirally thickened. The xylem strands are mesarch tracheides being present outside the protoxylem and in contact with it. The centripetal portion is isolated from the protoxylem by a few cells of parenchyma. The phloem zone is represented by a few layers of dense brown crushed cells and is followed by a pericyclic layer of large clear cells. In this stem no secondary wood has been developed.

The Vascular Bundles One section contains several leaf traces still in the cortical zone. The phloem appears to be confined to the outer portion of the bundle in an arc around the single protoxylem point. Further out in the cortex the protoxylem splits into two portions but the bundle remains collateral.

The Cortex The inner cortex is a broad band of small parenchymatous cells traversed by large conspicuous bands of dark thick walled sclerotic cells. These plates of sclerotic cells are horizontally elongated and follow each other in regular vertical series. The outer cortex is of the typical *Dictyoxylon* type consisting of radial bands of dark brown thickened fibres and parenchymatous tissue.

The occurrence of the seed *Sphaerostoma ovale* Benson together with the fact of the leaf trace consisting of a single strand is conclusive evidence of the plant being *Heterangium Grevii*.

Sphaerostoma ovale M. Benson (Pl I Fig 4)¹⁰. The seed as is usual is incomplete the enveloping cupule or outer integument being lost. The section passed obliquely through the lower portion of the testa the outline being nearly circular with a diameter of 1.25 mm.

The Testa The epidermal layer of the ovule is not well preserved but consists of a regular row of palisade cells each of which carries a dark and apparently structureless process or hair. Many of the outer cells have their walls disrupted and the mucilaginous contents of the cells can be seen adhering to the hairs.

The Embryo sac The megasporangium is preserved as a dense brown structureless ring which has

PLATE I



LK 1



LK 2



LK 3



LK 4

expanded until its contour has been determined by contact with the surrounding vascular bundles. It is totally devoid of contents and is accompanied by a patch of disorganized cells which appear to be continuous with the inner wall of the inner integument and through which the vascular bundles rise obliquely.

The Vascular Ring System The megasporangium membrane is invested by five vascular bundles cut at various angles and connected with one another by sheath-like strips of tissue. This tissue appears to be of the same nature as the strands themselves, the vessels of both being very small and spirally thickened.

The section is probably cut through the region in which the bundles have begun to separate from the sheath-like investment of the base and is too low to show the splitting up of the bundles to form the eight or nine strands which traverse the remainder of the integument.

Transitional Forms of Heterangium In one of the fragmental pieces of coal ball material there occur some stems having undoubtedly affinities with the genus *Heterangium*.

After allowing for collapse under pressure the stems are roughly cylindrical in outline and are remarkable for the great development of the secondary wood zone. The stems vary from 4 mms to 8 mms in diameter, and little beyond the secondary wood is preserved. So far as can be seen, the central portion consists of a few small tracheides immersed in a disrupted mass of brown parenchymatous tissue. The secondary wood consists of large tracheides the walls of which are covered with multiserrate bordered pits, traversed by medullary rays, the largest of which divide the wood into sectors. It is of importance to note that despite the crushed appearance of the stems, it is only the central axis which has suffered, the secondary xylem being preserved practically intact. This fact, together with the unusual development of secondary wood, seems to indicate that we are dealing with transitional forms from *Heterangium* to *Lyginopteris* in which the central primary tracheides are greatly reduced in number and in which a

true pith was in process of formation

From the point of view of horizon alone these stems are of extreme interest by comparison with the transitional forms described by Dr Kubart ¹¹ (notably *Lyginopteris heterangroides*) from the Ostrau beds (Millstone Grit) of the Upper Carboniferous

Polydesmic *Heterangium* Petioles In the original nodule there are several detached petioles of *Heterangium* ¹², in only one of which, however, is the structure at all clear. This is an elongated petiole measuring 4 x 5 mm^s in transverse section and is incomplete at one end.

The petiole is concave on one side, convex on the other with an emergence bordered by thick walled epidermal cells. The ground tissue of the petiole consists of large thin-walled cells of parenchyma in which plates of sclerotic cells occur.

The hypoderma of the outer or convex side consists of thick walled elements through which the parenchyma of the interior finds its way as narrow radial bands. On the concave side the hypoderma seems to have practically disappeared, the internal parenchyma extending to the margin.

The complete end of the petiole contains two vascular strands near the extremity which are just separating from one another and are still connected by a thread of xylem. To preserve the symmetry of the petiole there must have been a corresponding couple of strands at the other end of the petiole, i.e., the petiole was polydesmic, with a leaf-trace consisting of four bundles. The bundles appear to be of the typical mesarch *Heterangium* structure with extremely little centrifugal xylem.

The presence of this petiole serves to link up the contained flora with that of the Coal Measures where the chief characteristic of the *Heterangium* species is the polydesmic nature of the petiole.

Lyginopteris oldhamia No stems have been discovered but the plant is well represented by scattered petioles, laminae and the characteristic "glands".

The Petioles Several transverse sections of incom-

plete petioles are present which exhibit all the characteristic features of *Rachiopteris aspera*, now known to be the petiole of *Lyginopteris oldhamia*

The surface of the petiole is slightly grooved and bears the well-known emergences. The outer cortex is composed of the typical Dictyoxylon or "Roman numeral" structure, dark radial bands of thick-walled cells separated by thinner bands of parenchymatous tissue. The vascular bundle assumes the form of a "W" with a concentric structure, the protoxylem groups occupying the lower convex portions of the bundle. In one case the bundle has begun to separate to form two equal sized "V" shaped bundles. In another section the bundle is still concentric with the protoxylem groups on the convex outer side but it has assumed an elongated structure in preparation for branching into the leaflets. The emergences are still present but the sclerotic plates have disappeared and the Dictyoxylon cortex is reduced to practically a single layer.

The Leaflets. The laminae are markedly dorsiventral with lobed extremities and emergences on the lower surfaces. Towards the upper convex surface the mesophyll consists of loosely packed cells elongated at right angles to the surface, i.e., palisade tissue. The spongy parenchyma of the under surface consists of cells which are more irregular, leaving intercellular spaces.

The epidermis consists of square cells with thickened walls and in one or two places on the under surface stomata are present. A hypodermal layer is present between the epidermis and the palisade tissue. In each of the swollen extremities a vascular strand is present lying almost at right angles to the section of the lamina, which is transverse. The xylem is enlarged, the tracheides being wide and short and the spiral ornamentation is thus clearly shown. The large cells forming a protective sheath to the strand are observable on the upper side but the more delicate phloem is not well preserved.

The Glandular Emergences. These characteristic spines are present on the petioles, rachis and the under surface of the leaflets. They have no vascular supply and are usually

triangular in outline with a broad base at the point of attachment. The spines have a thick-walled epidermis enclosing a mass of thin-walled cellular tissue. When complete they terminate in an enlarged glandular head which is filled with small rounded cells supposed to have been secretory tissue. In some cases the spine supporting the head is very long with a constricted neck just below the head and having stomata in the epidermis.

Lepidodendron cf. Veltheimianum, Sternberg. The genus *Lepidodendron* is represented only by very fragmentary portions of the stele, leaf-bases and cone. The portion of stele preserved exhibits the characteristic primary xylem cylinder in which the protoxylem occupies the bays of the irregularly crenulate margin; there is no indication of secondary wood.

The detached leaf-bases or cushions are of the shield-shaped Lepidodendroid type with the central vascular bundle and lateral parichnos prints. Immediately above the tracheides of the vascular strand are the much smaller and more inclined tracheides of the ligule. Radial sections of leaf-bases are present in which the ligule is preserved at the base of the ligular cavity.

One section contains a poorly preserved strobilus (*Lepidostrobus cf. Veltheimianus?*) consisting of fragments of sporophylls, collapsed microsporangia and numerous detached microspores.

Megaspores are present which are large in comparison with the microspores and are densely clad with blunt, curved spines.

Stigmaria ficoides Bgt. (Pl. II. Figs. 1 & 2.) In the true coalballs Stigmariian rootlets are prevalent, while in the floor nodules they appear to be the only plant structure present. Usually the only portion remaining intact is the secondary wood, divided into wedged-shaped bundles by the medullary rays. The elements are arranged in radial rows and gradually increase in size from the interior outwards. The primary xylem merges gradually into the secondary wood and occurs as smaller and less regularly arranged cells at the inner end of the wedges.

PLATE II



Fig. 1

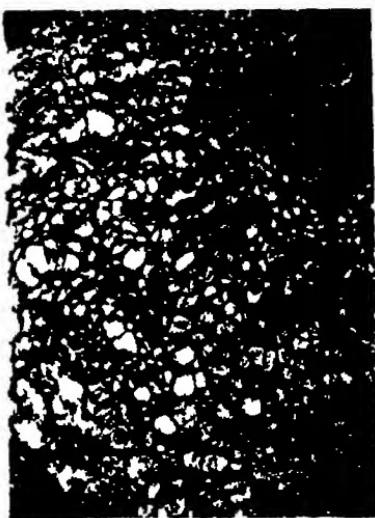


Fig. 2



Fig. 3



Fig. 4



Fig. 5

An interesting section, probably cut through the base of a rootlet recalls *Xenophyton radiculosum* Hick in that the whole of the structure is preserved from the vascular axis to the outer cortex. The xylem consists of a pear-shaped group of tracheides with the protoxylem at the apex and a few radially arranged cells of secondary wood along the opposite margin. The protoxylem is in direct contact with the parenchyma of the inner cortex, the phloem forming an arc around the secondary wood. The inner cortex forms a band of closely packed cells eight to ten layers in thickness arranged in crescentic form around the stele, assuming the pear shaped structure of the vascular bundle. The protoxylem point projects slightly into the inner cortex and tails off into one or more isolated tracheides indicating the presence of a tracheide strand leading through the middle cortex to the peripheral layers.

The middle cortex is perfectly preserved and is divisible into two zones, an inner zone consisting of polygonal or approximately square cells with intercellular spaces and in which no definite arrangement into layers can be observed, and an outer zone in which the cells are greatly elongated radially and are filled with a brown substance. This zone is by far the most prominent feature of the rootlet and there can be little doubt that this growth is of a secondary nature due to meristematic action in the outer layers of the middle cortex. The outer cortex consists of an inner band, four or five cells in width, with thickened walls and filled with dense brown material, the outer layers being larger and clearer parenchymatous cells.

Botrychioxylon paradoxum, D H Scott (Pl II Fig 3)¹² The section is perfectly transverse and consists of an approximately circular stele, all the cortical tissues having been destroyed. The characteristic features of *Botrychioxylon paradoxum* are clearly indicated in the presence of a "mixed pith" surrounded by a zone of radially serrated wood. This mixed pith consists of intermingled parenchyma and small tracheides. The internal tracheides vary in size from about 30 to 40 μ in diameter, the parenchyma on the whole being less than 30 μ . The outer border of the

mixed pith is fairly well defined by the presence of several protoxylem groups which protrude into the zone of secondary wood and give the line of contact a crenulate appearance.

The whole of the secondary wood assumes a radially seriate structure, each element being elongated in a radial direction. One side of this zone has been destroyed, but, by the diminution in size of the tracheides, it is evident that the development of the secondary wood about the central axis was unequal.

In the gaps between the protoxylem points, the internal tracheides of the mixed pith appear to break through and continue throughout the secondary wood in the form of narrow rays. The protoxylem groups consist of four or five very small tracheides varying in size from 8 to 16 μ and their position on rather prominent angles of the mixed pith indicates that in all probability the internal primary xylem was developed centripetally as was suggested by Scott in his original paper.

Dineuron ellipticum, Kidston. (Pl. II. Figs. 4 & 5)¹² This genus appears to be represented in Britain solely by the type specimen obtained from the Calciferous Sandstone Series of Pettycur Fife and described by the late Dr. Kidston. Thus the specimen to be described from the higher horizon of the Little Limestone Coal is of more than usual interest.

It is, unfortunately, incomplete, consisting as it does of a single obliquely transverse section of an elliptical foliar bundle in which most of the external tissues have been destroyed.

The bundle has a length of some 2 mms. and an average diameter of .7 mms. The xylem consists of large and rather irregularly shaped tracheides which decrease considerably in size towards the poles where the protoxylem points are situated. The diameter of the tracheides of the metaxylem varies from about 180 to 30 μ while the protoxylem elements range from 30 to about 12 μ .

One pole of the foliar bundle together with its protoxylem point has been destroyed. The slight obliquity of the

section shows that the tracheides of the metaxylem are ornamented with multiseriate pits and that the wood is solid and free from any trace of intermingled parenchyma

The protoxylem point is not situated quite at the extremity but is immersed in the metaxylem, i.e., a few tracheides separate it from the cortical zone. This portion of the metaxylem is in the form of an arc bounded by two strands originating in the protoxylem and passing out at such a low angle that the scalariform sculpture is clearly shown.

Dr Kidston in his paper on *Dimuroeon ellipticum*¹³ suggested, by analogy with *Lygopteris Metaclepsydropsis duplex*, Will "that a band was cut off alternately from each end of the xylem to supply the pinna traces, which possibly divided into two in their course through the cortex".

In the specimen described there seems to be no room for doubt that the pinnae trace was double at its departure from the protoxylem and that it carried some of the metaxylem with it into the cortical zone.

The bundle is surrounded by a mass of dense cells with a dark brown content which may be the remains of thick-walled prosenchyma originally forming the outer cortex.

4. *The Character of the Flora*. In examining the material the first point of note is the complete dominance of the Ferns and Pteridosperms as represented by *Stauropterus* and *Heterangium* respectively. No recognisable remains of Calamites or Sphenophylls have been found and the *Lycopods* are scantily represented by fragments of sporangia and leaf bases of *Lepidodendron*.

A poorly preserved strobilus is present which may indicate the presence of *Lepidostrobus Veltheimianus*, a species very common in the Pettycur deposits.

Among the Pteridosperms the only *Heterangium* determined is the Lower Carboniferous species, *Heterangium Grievii*, Williamson, which is characterised by the leaf-trace remaining single throughout its course. Additional confirmation is provided by the presence of *Sphaerostoma ovale* Benson, the probable seed of *Heterangium Grievii*. Several crushed stems are present which are believed to be of

Heterangoid type with a remarkable development of the secondary wood. They appear to be comparable with the transitional form *Lyginopteris heterangoides*, described by Kubart from the Millstone Grit of Ostrau, Upper Silesia. A leaflet, unfortunately incomplete, occurs in which there are decided indications of the presence of four vascular strands, i.e., it was polydesmic—a characteristic feature of the Coal Measure Heterangiaceae.

The only Pteridosperm definitely of Coal Measure type is *Lyginopteris oldhamia* which is well represented by petioles and laminæ bearing the characteristic glandular emergences.

The Ferns are represented by *Dineuron ellipticum*, Kidston, previously recorded from the Pettycur deposits and *Botrychioxylon paradoxum*, Scott, remarkable for its development of secondary wood, from the Lower Coal Measures of Lancashire. In the case of *Stauropteris*, the presence of *Bensonites fusiformis* an organ believed to be of a glandular nature, is of importance in that it is constantly found in association with *Stauropteris burntislandica* from the Pettycur beds, but has never been found with *Stauropteris oldhamia* of the Coal Measures. On the other hand some of the specimens exhibit the wedging apart of the cruciform xylem which characterises the Coal Measure form, and give no indication of the protoxylem canals found in *Stauropteris burntislandica*. Hence it is probable that both the Lower and Upper Carboniferous forms are present in the material. From the comparative table given it will be seen that there is quite a representative proportion of Intermediate and Upper Carboniferous forms and one is therefore justified in stating that the flora was in a state of transition. That this change in type had just begun is evident from the fact that, from the point of view of frequency of occurrence, i.e., relative number of specimens present in the material, the flora is still quite 90% of Lower Carboniferous type. For purposes of comparison the list of species obtained from the Little Limestone horizon is given together with the previously recorded horizons in Great Britain.

5 Recorded Horizons of Species obtained from the Little Limestone Coal

Species	Calc	Sandst	Lower Coal Meas.
<i>Stauropetis burntislandica</i> , Bert	X	—	—
<i>Bensonites fusiformis</i> , Scott	X	—	—
<i>Stauropetis oldhamia</i> , Binny	—	—	X
<i>Heterangium Grevii</i> , Williamson	X	—	—
<i>Sphaerostoma ovale</i> , Benson	X	—	—
Transitional Heterangiums	(Millstone Grit, Kubart)		
Polydesmic Heterangiums	—	X	
<i>Lyginopteris oldhamia</i> , Binney	—	X	
<i>Botrychoxylon paradoxum</i> , Scott	—	X	
<i>Dineuron ellipticum</i> , Kidston	X	—	—
<i>Stigmaria ficoides</i> , Bgt	X	—	X
<i>Lepidostrobus cf Veltheimianus</i>	X	—	

The absence of tall trees such as the giant Lycopods and Calamites suggests that the flora may have been of a foothill or lower upland type in which the moderately tall Pteridosperms were invested by a dense growth of the tree ferns of various types from long, clinging rhizomes to short, stout stems covered with leaf bases

SUMMARY

1 The material examined constitutes the first record of the occurrence in Northumberland of the plant-bearing calcareous nodules known as "coal-balls"

2 The horizon of the material is that of the Little Limestone Coal in the Upper Bernician of the Lower Carboniferous Series Locality The South Tyne Colliery Haltwhistle

3 The following plants are represented in the flora —

Stauropetis burntislandica, Bert

Bensonites fusiformis, Scott

Stauropetis oldhamia, Binney

Heterangium Grevii, Williamson

Sphaerostoma ovale, Benson

Transitional Heterangiums (Kubart)

- Lyginopteris oldhamia*, Binney.
Botrychioxylon paradoxum, Scott.
Dineuron ellipticum, Kidston.
Stigmaria ficoides, Bgt.
Lepidodendron cf. Veltheimianum.

4. The flora, while still predominantly Lower Carboniferous in type, has reached a transitional stage between Lower and Upper Carboniferous forms.

ACKNOWLEDGEMENTS.

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In conclusion I wish to place on record my indebtedness to the Council of Armstrong College, Newcastle-upon-Tyne, who rendered possible the pursuit of this investigation by the award of Research Studentships in 1925 and 1926.

EXPLANATION OF PLATES.

PLATE I.

- Fig. 1. *Stauropteris burntislandica*. (P. Bertrand). Transverse section of rachis showing two protoxylem groups at each angle of the xylem. ($\times 40$.)
- Fig. 2. *Bensonites fusiformis*. (R. Scott.) A fused pair showing the multicellular bodies, each with a head and a beak. A delicate vascular strand leading from the head is lost in the cells of the body. ($\times 50$.)
- Fig. 3. *Heterangium grievi*. (Williamson.) Obliquely transverse section showing the central primary xylem of mixed tracheides and parenchyma, the cortex with sclerotic bands and two leaf-traces passing out. ($\times 10$.)

Fig. 4. *Sphaerostoma ovale*. (Benson.) Obliquely transverse section of testa containing the megaspore membrane invested by five vascular bundles. ($\times 50$.)

PLATE II.

Fig. 1. *Stigmaria ficoides*. (Brongniart.) Transverse section of rootlet showing the vascular bundle and fully preserved middle and outer cortex. ($\times 18$.)

Fig. 2. *Stigmaria ficoides*. (Brongniart.) Median zone, showing aereocluyina. ($\times 50$.)

Fig. 3. *Botrychioxylon paradoxum*. (Scott.) Transverse section showing the mixed pith with several protoxylem points around the margin followed by radial seriate secondary wood. ($\times 80$.)

Fig. 4. *Dineuron ellipticum*. Showing general form of stele. ($\times 40$.)

Fig. 5. *Dineuron ellipticum*. Showing protoxylem and reticulate-scalariform tracheids. ($\times 110$.)

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WATER-HAMMER EROSION

By STANLEY COOK F.R.S

Introduction

Certain investigations which the Author has made or with which he has been associated have brought to light the remarkable possibilities possessed by nearly incompressible fluids, arising entirely from mechanical considerations, of producing locally, and under certain circumstances, pressures which are so considerably in excess of those arising from the normal motion of the fluid as to suggest that in the event of their being in excess of the yield-point strengths of ordinary materials they may prove the real cause of many appearances of erosion not otherwise explained. The object of the present note is to shew that in the case of corrosive or erosive action observed to be promoted by the motion of metal surfaces in water, or by the motion of water over such surfaces, and frequently attributed to corrosion through a failure to recognise any cause of a mechanical nature sufficient to produce it, in many instances a satisfactory explanation of such action can be advanced by associating it with the phenomenon known as water-hammer.

Water-hammer The sudden arrest of a column of incompressible fluid would, apart from elasticity at the surface of the body arresting it, produce an infinite force. That force, however, is rendered finite in the case of water by the slight degree of compressibility, and can be readily calculated. In the initial impact of a moving column against a fixed obstacle, assuming no intervening gas to cushion the blow, the column is arrested first at the end and subsequently, as the disturbance travels back, throughout its length, the velocity energy of the front layer is in this case converted on impact into pressure energy in that same layer. Since the velocity energy per unit volume is equal to $\frac{1}{2} \rho V^2$ and the potential energy after arrest to $\frac{1}{2} \beta p^2$ where ρ is the density of the liquid and β its compressibility, the equation of these gives $\frac{1}{2} \beta p^2 = \frac{1}{2} \rho V^2$ or in other words the pressure generated at the end of the column by the

impact is equal to $V\sqrt{\frac{\rho}{\beta}}$. The whole column will be arrested and its pressure brought up to this value, when the disturbance has travelled to the far end, that is to say, in the time $\frac{l}{c}$ where l is the length of the column, and c is the velocity of sound in the liquid. The impact pressure at the front end of the column endures for a time $2\frac{l}{c}$, or the time required for the disturbance to travel to the outer end of the column and back again.

Comparison with a jet. The impact pressure of a column of water under these conditions is an entirely different thing from the pressure corresponding to the momentum of a jet. It is the first impact that constitutes the blow, and the suddenness and therefore the force of this blow depends upon the degree of incompressibility of the fluid. A steadily impinging jet on the other hand is arrested gradually, by the increase in pressure in the portions of it which are nearest to the surface on which it impinges and the jet is spread on the plate over a much larger area than the section of the column. In the case of such a jet impinging on a flat surface the maximum pressure on the surface will occur at the centre of the jet, viz. at the end of the axial stream line, and will be the pressure corresponding to the velocity head, equal therefore to $\frac{1}{2}\rho V^2$. So that such a jet will require to have a higher velocity V_1 given by $\frac{1}{2}\rho V_1^2 = V\sqrt{\frac{\rho}{\beta}}$ in order that it may produce the same maximum local pressure, and even then that pressure will be confined to a mathematical point at the intersection of the surface by the axis of the jet, so that it may be asserted that a higher velocity than V_1 would be required to produce the same local pressure as is attained by the first impact of a column of fluid at velocity V . The above relation gives $V_1 = \sqrt{\frac{V^2}{2} + c^2}$ where c = velocity of sound. Thus if $V = 200$ metres per second producing a pressure on first impact of 2800 atmospheres, a steadily impinging jet

would require to have a velocity of more than 750 metres per second to produce the same pressure.

It is interesting to note too that the water-hammer pressure is independent of the length of the column. It follows that drops of water however minute will at the first moment of impact produce the same water-hammer pressure as large volumes of water with the same velocity, the only difference being in the area of attack and the duration.

As an example of the order of value of such pressures taking $\rho = 1$ and $\beta = \text{approximately } \frac{1}{20,000}$ per atmosphere of pressure a velocity of only 10 metres per second gives an impact pressure of 140 atmospheres, 200 metres per second gives 2800 atmospheres, the latter pressure being about 18 tons per square inch.

Erosion of turbine blades. Erosion of turbine blades has been understood for some time to be due to water of condensation, and its character indicating a bombardment of the backs of the blades it was inferred that it was due to the blades striking drops of water. But the calculation of pressure of hydraulic impingement at such speeds as corresponded with the speed of rotation of the blades failed to account for a destructive force on the blade, and the phenomenon looked at from this point of view appeared a mysterious one. The far higher local pressures attained on first impact, i.e. by water-hammer, are now seen to be sufficient to explain the circumstances.¹

In the case of the steam turbine erosion is frequently found to have occurred on a few of the moving blades at the exhaust end. On the outer portion of the moving blades at the exhaust end the leading edges are found to be thickly honeycombed with minute indentations of conical shape of varying depths and are sometimes completely perforated, the action occurring on the convex surface of the blade, that is to say, on the side towards which the blade is moving. It occurs chiefly at peripheral speeds in excess of about 120 metres per second, and is of increasing intensity as the speed is increased.

It is now accepted that this erosion of the blade surface is due to impact in high vacuum of drops of water arising from condensation of the steam by expansion, which drops moving at a lower velocity, in fact without any appreciable circumferential velocity, are overtaken by the rotating blade. It has already been pointed out that the water-hammer pressure due to the impact of a drop is the same as for a larger volume, depending only upon the velocity. The water-hammer pressure by the foregoing formula, at 120 metres per second is 1700 atmospheres or about 11 tons per square inch, which is of the order of the elastic limit of many metals.

In order to investigate the erosion produced by a multitude of minute drops impacting on metal at high velocity, the following experiment has been made. The apparatus consisted of a ring of turbine blades mounted on a shaft and rotated at a high speed within a cylindrical casing. At two diametrically opposed points in one end wall of this casing two sprayers of the "White" oil-fuel burner type were used to project a fine spray of water across the moving blades. The blades were widely separated in the circumferential direction to give the spray access to their surfaces. This was necessary because the high speed of motion of the blades made the relative direction of impingement of the water drops nearly circumferential. The bladed rotor thus represented an exhaust-end element of a steam turbine from which two out of every three blades were removed. The rotor was 12 inches in diameter and the blades 4 inches high. The axes of the water sprayers were situated at a distance of 8 inches from the axis of the rotor.

The apparatus was run for 18½ hours at a speed of 8,800 revolutions per minute, so that the speed of impact varied from 140 metres per second at the roots of the blades to 238 metres per second at the tips. By the formula given above the corresponding water-hammer pressures are 12·4 tons per square inch to 20·7 tons per square inch.

The blades were of five different materials as given below:—

Material of blades.	Elastic limit. Tons/sq. inch	Condition after test.
1. "Hecla A.T.V." steel	31	Unattacked.
2. Tungsten steel .	40	Rusted and slightly eroded.
3. "Staybrite" steel .	16	Considerably eroded.
4. Monel metal ..	18	Considerably eroded.
5. Mild steel . .	16	Etched as by sand blast.

Fig. 1 is a photograph of the rotor after test, the blade at the top and the one to the left of it are of "Monel" metal, the next two to the right are of "Staybrite" steel, whilst the next two to the left are of mild steel sheathed with "Hecla" steel on their leading edges.

Collapsing Cavities Extension of the problem to three dimensions introduces the important factor of concentration. If the liquid instead of moving in a column as in an uniform tube, is moving in a conically shaped tube, the velocity of the front layer will increase rapidly as it approaches the apex. The same is true if it is closing in on a spherical cavity. The case of a spherical cavity suddenly permitted to collapse represents a condition of things that may arise for example when a propeller blade cuts across a vortex core in such a way as to isolate a vacuous cavity and at the same time destroy the vortical motion. Or a sudden arrest of flow of water in a tube by stoppage of the inlet would, by the momentum of the water, tend to break the continuity of the fluid and create cavities which would immediately afterwards tend to collapse. The work done by the surrounding fluid closing in as the cavity collapses is converted into velocity energy, and since, in an incompressible fluid moving symmetrically towards a fixed point, the velocity varies inversely as the square of the distance from that point, this velocity energy will be found mainly concentrated at the reduced surface of the cavity. In the case of an incompressible fluid the velocity at the reduced surface of



Fig. 1



A
Fig. 3

such a cavity at any subsequent time, when its radius R , may be shown to be $\sqrt{\frac{2P}{3\rho}(R_0^3 - R^3)/R^3}$ where P = the pressure

in the surrounding fluid and R_0 the initial value of the radius (see appendix) Thus for $R = R_0/20$ and $P = 1$ atmosphere the velocity at the final surface of the cavity = 780 metres per second, and supposing the cavity to collapse finally on a surface with this velocity (we might, for example consider a hemispherical cavity collapsing on to the surface of a propeller blade in the diametral plane) it was further shown that the water-hammer pressure thus produced would be as high as 10 000 atmospheres or roughly 65 tons per square inch In such a case the final act of erosion is due to water hammer, but the concentration has the effect of enormously increasing the velocity in the final stage of collapse and making the water hammer more intense

Suppose that the free surface impinged on a sphere of radius R , the pressure of impact is then given by

$$\frac{1}{2} \beta p^2 = \frac{1}{2} \rho \left(\frac{dR}{dt} \right)^2$$

$$= \frac{P}{3} \left(\frac{R_0^3 - R^3}{R^3} \right)$$

$$\text{so that } p = \sqrt{\frac{2P}{3\beta} \cdot \frac{R_0^3 - R^3}{R^3}}$$

or if R is so small that $\frac{R^3}{R_0^3}$ can be neglected

$$p = \sqrt{\frac{2P}{3\beta} \cdot \frac{R_0^3}{R^3}}$$

In the last stages of collapse when the radius of the cavity is extremely small, a steep pressure gradient extends outwards from the surface, and it is no longer possible to neglect the compressibility of the fluid Some of the energy

has been absorbed in potential energy of the surrounding fluid extending a very short distance out from the surface of the cavity, and the final velocity is therefore somewhat less than on the assumption of incompressibility.

If however we assume that the whole of the energy of collapse viz. $P\bar{V}$, where \bar{V}_0 = original volume of the cavity is absorbed in potential energy of a small final volume \bar{V} viz.

$$\frac{1}{2} \beta p^2 \cdot \bar{V} \text{ we obtain a value for } p = \sqrt{\frac{2P}{\beta}} \cdot \frac{\bar{V}_0}{\bar{V}}$$

that even taking compressibility into account the pressure of impact will be of the same high order as is given by the preceding equation.

The following are values of p for various values of

$$R/R_0 \text{ with } P = 1 \text{ atmosphere, } \beta = \frac{1}{20,000}$$

R/R_0	p (atmospheres)	p (tons per square inch).
.5	306	2.0
.1	3,650	24
.05	10,300	67
.01	115,000	750

The final velocity and the final impact pressure will be seen to depend upon the original size of the cavity in relation to the final radius and therefore probably in relation to the coarseness of the structure of the metal on the surface of which it is collapsing.

The behaviour and effect of such cavities was first considered in connection with the investigation of propeller blade erosion by a committee appointed by the Admiralty in 1915. Fig. 2 illustrates the water-hammer cone devised by the Hon. Sir Charles A. Parsons, the Chairman of that committee, for obtaining a practical demonstration of high pressures produced in this way by the

combined effects of concentration and water hammer A is a brass cone 18 inches long and $2\frac{1}{2}$ inches internal diameter at the large end, extended at the large end by a cylindrical portion to a total length of 4 feet, this cone is reinforced at the small end and fitted with an end piece, B, terminating with a small hole of 015 inches diameter This cone placed under water in a tank, after filling with water was thrust quickly downwards, its mouth striking on to a rubber block at the bottom of the tank The momentum of the water, augmented in the later experiments by that of the lead plunger J, produced momentarily a cavity at the apex, which however immediately closed again It was found possible to puncture thin plates of metal at the apex and in this way some idea was obtained of the pressure induced by the impact of the water With a cone end piece of oil hardened tungsten steel having a smallest diameter of 015", a brass plate 03 thick was punctured at a single blow, and a plate 035" thick in two blows, the first blow having been sufficient to extrude the metal a distance nearly equal to the thickness of the plate The pressure required to produce direct shear of the

$$\text{periphery of the hole in the plate} = \frac{035}{015} \times 4 \quad 9.35 \text{ times}$$

the shearing strength of the material taking the latter at 15 tons per square inch the pressure generated must have been at least 140 tons per square inch

It appears from the foregoing considerations that arising from the mechanical properties of nearly incompressible fluids local water-hammer pressure is a powerful factor contributing to erosion and that where the conditions are such that cavities may form in the water and subsequently collapse in the neighbourhood of metallic surfaces there is the possibility of much higher velocities in the water locally than are normal to the general conditions, and, in addition, the certainty that wherever such high velocities are destroyed by the interposition of a surface, intense momentary pressures will be set up by the water-hammer effect above referred to

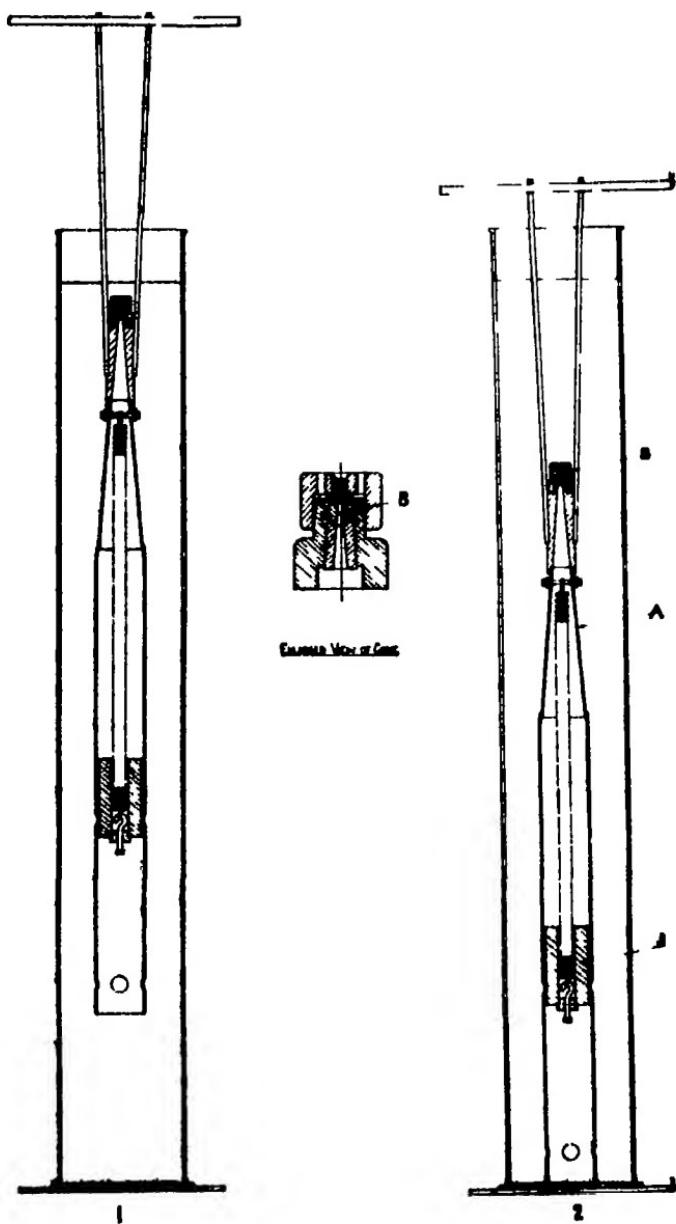


Fig. 2

These investigations and experiments convinced the Committee referred to above that the deterioration of propeller blades of cruisers and destroyers by erosion was due to water-hammer effects resulting from cavitation.

Rapid erosion of the same character as on propeller blades, frequently encountered on the runners, casings and liners of centrifugal pumps, screw pumps and hydraulic turbines, can also be satisfactorily accounted for in the same manner.

Returning now to the case of the erosion of steam turbine blades it is clear that this erosion cannot be due to such drops of water as are carried in the main stream of the steam through the blade passages since such drops issuing from the blades at the same speed as the steam would not be overtaken by the moving blades. A large proportion of the water of condensation forming in a mist of minute drops would be carried along by the steam in this manner and would not contribute to the erosion. From this consideration and from the fact that erosion is only found to occur on the moving blade, it must be attributed to drops of water which are swept off the fixed blades into the path of the moving blades, and which do not so partake of the general velocity of the steam.

Whilst minute drops of water assume a practically spherical shape on account of surface tension, drops formed in the manner suggested may be of moderate dimensions and under these circumstances a slight departure from the spherical shape may be expected. With drops of irregular shape, or even if there are minute surface irregularities on the blades themselves, there is the possibility of the isolation of small empty spaces between the drop and the blade at the moment of impact, in which case the behaviour subsequent to impact would be that of a collapsing cavity with the final generation of much higher water-hammer pressures.

Figure 3 illustrates the progress towards final collapse after impingement, as it might be conjectured to take place with a drop of this character. In the final stages the

concentration of the motion towards the centre of collapse at A will produce high velocities at the surface of the entrapped cavity, and finally water-hammer at A

Further, when a conical depression has once been formed it is clear that it will be rapidly deepened by drops that may strike directly into it or over its mouth, since concentration will then have its full effect in producing a high final velocity

In a paper read by Sir Charles Parsons before the Institution of Naval Architects in 1927² some investigations are described in regard to the cause of pitting of condenser tubes, which go to show that irregularity of flow and vortex motion in the water box of a surface condenser may cause considerable variations of flow through the tubes, the flow through a tube being momentarily checked when a vortex in the box moves across its mouth, with consequent breakages of continuity of the water near the inlet end of the tube and subsequent collapse of the cavities so created, producing water-hammer effects

Whilst it is generally held that occluded gases play an important part in the pitting of brass condenser tubes, and certainly there are in most cases distinct evidences of corrosion, oxidation and dezincification being found to have occurred near the pits, the causes just mentioned are sufficient to account for pitting of a purely mechanical nature, and it may be that occluded gases compressed to a high pressure and possibly to a high temperature at the final collapse of a cavity are brought to a state of high chemical activity so that both corrosion and erosion result from the same causes

The late Lord Rayleigh discussed the case³ in which a spherical cavity, instead of being vacuous, contains a small amount of gas, in which case the velocity of the boundary comes again to zero before complete collapse, the whole of the energy of collapse having been converted into the pressure energy of this imprisoned gas. The final volume is shewn to be extremely small when the initial pressure of the gas is only a small fraction of that of the

surrounding fluid. It was, however, assumed that the compression of this gas would take place isothermally, whereas, in the last stages of the compression at any rate, the interval of time during which it takes place being usually extremely small, compression is probably adiabatic, and a high temperature will be reached as well as a high pressure.

It will be seen from the examples mentioned that the phenomenon of water hammer and the formation and collapse of cavities in water intensifying the water-hammer in the manner described furnish ample material for the explanation of many cases of both corrosion and erosion of metallic surfaces exposed in various ways to such conditions.

In conclusion the author wishes to acknowledge his indebtedness first of all to Sir Charles Parsons, who really initiated this line of investigation, to Messrs Parsons Marine Steam Turbine Co., and Messrs C A Parsons & Co., for facilities for experiments, and to Dr Gerald Stoney and Mr R Dowson of the latter firm for much kind and valuable assistance.

APPENDIX

Conditions of collapse of vacuous spherical cavities

The general dynamic equations for an incompressible fluid with motion everywhere a function of radius and time only, are

$$-\frac{dp}{\rho dr} = \frac{du}{dt} + u \frac{du}{dr} \quad (1)$$

$$\text{and } ur^2 = f, \text{ a function of time only} \quad (2)$$

Assuming the fluid to extend to infinity, and to have a free internal surface at the surface of a sphere of radius R the

radial velocity of this free surface being $\frac{dR}{dt}$, then $ur^2 = f = \frac{dR}{dt}$. Equation (1) on integration with respect to r' gives

Equation (1) on integration with respect to r gives

$$\frac{p^1 - p}{\rho} = - \frac{1}{r} \frac{df}{dt} + \frac{1}{2} u^2 \quad (5)$$

Putting $p=0$ at the free surface and $r=R$

$$\frac{df}{dt} = \frac{d}{dt} \left(R^2 \frac{dK}{dt} \right) = \frac{1}{2} R \left(\frac{dR}{dt} \right)^2 - \frac{p^1}{\rho} R$$

$$\text{from which } R \frac{d^3R}{dt^3} + \frac{3}{2} \left(\frac{dR}{dt} \right)^2 + \frac{p^1}{\rho} = 0 \quad (5)$$

The first integral of equation (5) is

$$\left(\frac{dR}{dt} \right)^2 = \frac{2p^1}{3\rho} \cdot \frac{R^3 - R^6}{R^3}$$

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A NEW ROSE FROM NORTHUMBERLAND

By KATHLEEN B BLACKBURN, D Sc

The rose flora of this district is so rich that it is not very surprising to find new and undescribed forms. Some of these are obviously of recent hybrid origin, but the one here described and illustrated shows no evidence of being such and seems to be a good new micro species. I have to thank Professor J W Heslop Harrison for ascertaining that it is not only new to Britain, but also unknown abroad, and also for suggesting an appropriate name. I should also like to thank Miss C M Shipley for very kindly looking through the Latin Diagnosis which follows.

Rosa berniciensis, Blackburn var nova. Caulis et ramorum aculei curvati, falcatique, ramæ florentes etiam aculeis parvis et tenuibus aciculisque sparsis muniti. Folia plerumque septenata, rarius quinata, stipulæ angustæ, cum auriculis acutissimis, in margine glanduloso-ciliatae foliola mediocria, ovato-elliptica, (20×12 mm usque 30×15 mm) subtus glandulosa sed sub nervo medio setoso-glandulosa, biserrata, petiolæ pubescentes glandulosi, pedunculi breves, setoso-glandulosi, bracteis acutis angustisque superatæ, sepala pinnatifida, glanduloso-ciliata, in fructu patentia vel reflexa, denique cadentia, receptacula globosa, bene fructifera, discus planus stylæ breves albo lanati vel villosi, capitulum planum formantes.

The plant was found in a roadside hedge a few miles north of Morpeth. It is a tall bush with much branched shoots. The branches are dark purple where exposed to sunlight and green below. The prickles are strongly hooked and light grey in colour. The flowering shoots bear some acicles in addition. The leaves bear 5 to 7 leaflets of which the lowest pair is often very small. The leaflets are glabrous, ovate elliptical and sometimes acute. The lower leaves of the flowering shoots are glandular below in Spring but the glands disappear later. The margins are strongly serrate with gland-tipped teeth, the midrib below is glandular aciculate and the petioles glandular and

hairy. The stipules have long narrow acute auricles erect or spreading and with hairy, heavily glandular, margins. The fertile shoots usually bear 1 to 3 flowers, less frequently 5 to 7. The peduncles are short and markedly glandular. The basal bract of the inflorescence has very broad stipules and three large leaflets, the upper ones are scale-like, lanceolate attenuate and progressively smaller and narrower, with glandular margins. The glabrous, light red, round fruit is surmounted by a small flat disk. The sepals are pinnate and hairy glandular all over, spreading or reflexed, falling when the fruit is completely ripe. The stigmas form a rather small flattish head and the styles are very hairy. The seeds are very numerous and all the flowers seem to have ripened fruit. The fruit was ripe later than that of the neighbouring *R. Reuteri* bushes but earlier than the various forms of *R. canina* and *R. dumetorum* growing near by.

The majority of our British roses belong to the Section Caninae and this one is no exception. Within the section are groups of forms which are considered as group species. The flat head of hairy stigmas and the short peduncles are enough to show that the plant in question belongs to the group species *Afzeliana*. Since the leaves are glabrous it belongs to that part of the group *Afzeliana* which is known as *Rosa glauca*. Within this species, since the sepals are spreading or reflexed, it belongs to the sub-species *R. subcanina*. The nearest micro-species or variety to *R. berniciensis* recorded in Woolley-Dod's list of the British roses is *R. denticulata*, Keller, which has biserrate leaflets but altogether lacks the acicles and glands on the flowering shoots. It differs from *R. glandulifera*, Keller, of Southern Europe in that the flowering shoots are strongly armed and the peduncles short. Thus the combination of characters found in *R. berniciensis* seems to be really new.

The plant might, of course, be a recent hybrid and the fact that, so far, only one bush is known is rather suggestive; on the other hand, the fact that every flower produces a hip full of good seeds weighs heavily on the other side of the scale. An investigation of the neighbouring bush-

es might be helpful in this connection On the one side was a bush of *R. dumetorum*, probably var *semiglabra* with round fruits giving a superficial resemblance, whereas on the other side was first a small plant of *R. omissa*, which may have been a hybrid, and then a thicket of typical *R. omissa*. *R. Reuteri* is in fair quantity not far off and *R. canina* forms exist some distance away To get a combination of characters such as would produce *R. berniciensis* by hybridity, *R. canina* or *R. dumetorum* would need to be included to give the spreading or reflexed sepals Hairy leaves and biserrate margins being dominant we should choose a biserrate canina form for one parent if *R. Reuteri* were to be the other With such a combination however, the glands would be absent since no glandular *canina* is known in the district

If a *canina* form were crossed with *R. omissa* the dominant hairiness would appear unless we were to suppose the *omissa* to be heterozygous for hairiness by being itself a cross with say *R. Reuteri* Although the one hybrid *omissa* bush was noted it gave no clear evidence of its parentage and it would seem a very frail foundation for such a suggestion of hybrid origin I prefer to retain my original view that the plant is not a recent hybrid Probably careful search of the district will show further examples of this very distinct form and so remove the possibility of reproach for having created another "bush-species"

CHEMISTRY AND LIFE.

By A. MEEK, D.Sc., S. TOMKEIEFF, F.G.S., and
M. THOMAS, M.A.

FOREWORD.

By A. MEEK, D.Sc.

We may have been expecting too much from the Bio-chemist. Mr. Tomkeieff as a geologist, presents the vastness of the subject of the biosphere in relation to the other geospheres and discusses besides the metastability of the biological unit. Mr. Thomas, as a bio-chemist, attacks the problem from within and comes rightly to the conclusion that the ambition of the chemist to synthesize protoplasm is one thing which he admits might be realised, but it is quite another to contemplate the formation of a particular kind of protoplasm. But apart from the circulation of material and the limitations of the subject, two correlated facts of consequence have long been apparent, and these serve to bring bio-chemistry into close touch with the problems of the biologist.

The one is that there is no definite protoplasm, the variations are as numerous as the types of living creatures. In addition, in each type there are cytological and histological modifications. Such may be special, but they are more usually parallel modifications of type. It ought therefore to be possible to define the types by chemical differences, and by the adoption and extension of the methods of the bacteriologist to indicate affinities more clearly than has yet been done, and so to emphasize or correct the conclusions of the morphologist.

The second fact is that the modifications of protoplasm have been and are produced by internal and external environmental changes. Food, temperature, and other factors are constantly affecting protoplasm, and the results may be gathered from the preference we exhibit as to the products of a locality and the experiences of the culturist. It follows that the history of life has been one of progressive change. The protoplasms of today have a history and that

brings us by another path to the contention of Mr Thomas

Obviously then, protoplasm is in the state of being impressed evanescently by environmental changes, and by modifications which may be of a more permanent character. Whether the response be a chemical or physical change or an alteration of growth, or some form of action, it is concerned with the nervous property of protoplasm.

Protoplasm is impressionable and responsive and in both respects concerns the bio chemist and the bio physicist.

Part I

THE INORGANIC SUBSTRATUM OF LIFE

By S TOMKEIEFF, F G S

I rom the point of view of emergent evolution, life, together with its concomitant inner aspect—mind, is the latest emergent quality of the progressive integration of matter into units of higher complexity. This unique property of "life" depends on a peculiar material organisation or "pattern" in space and time, i e both on form and function. It is the latter, the function or pattern in time, that distinguishes the living from the non-living. We can have a number of emergent qualities due to a spatial arrangement of material particles, such as in crystals, but this pattern (disregarding the thermal movement of particles) is a static one. On the other hand the pattern of living units is entirely a dynamic one. It can be compared to the form of a waterfall which preserves its identity while its material content is for ever changing.

In comparison with inorganic matter, living matter is extremely unstable. Life is a constant adjustment of metastable or even labile internal equilibria towards changing environment. The actual strength and power of living matter lies in this very metastability, which assumes stability only as a dynamic unit. This dynamic stability necessitates an enormous output of energy. Like a water-spout passing over the surface of the ocean, organisms engulf a constant stream of matter which passes through them and then goes back to the ocean of matter. Organ-

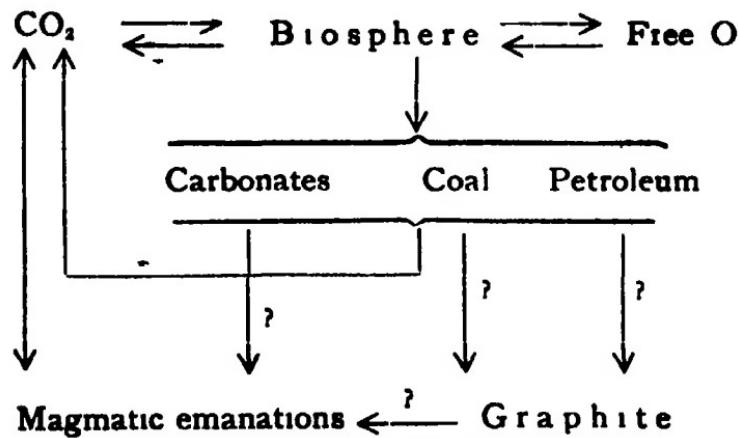
isms entirely depend on their material substratum, but they have the power to subtract or reject certain parts of matter with a resulting segregation or dissemination of elements in the earth's crust. The study of this complex series of interrelationships between the elements of the earth's crust and the total assemblage of organic beings—the biosphere, forms a part of a wider science of geo-chemistry. The biosphere, although a relatively small member of the earth, is nevertheless a very powerful factor in its history. Great thicknesses of rocks were formed through the agency of organisms, elements were segregated, dispersed, combined and set free—all through the same agency. At the present time we see life covering the surface of the earth, interpenetrating the seas, lakes, rivers, burrowing into the earth and conquering the air. But still only a very small portion of the earth is suitable as a habitat for life. The great bulk of the earth is composed of inert (crystalline?) matter. The sphere of activity of the biosphere is restricted to the outer zones of the earth. Nevertheless its importance as a geochemical factor is enormous. The biosphere is composed of countless individuals, each acting as a small centre of incessant activity, stirring up the surrounding matter which flows in a steady current through the biosphere.

The living matter is composed of elements mainly derived from the hydrosphere and the atmosphere, and the principal organogenic elements are as follows: O,H,C,N, while the lithospheric elements: Ca,S,P, Si,K,Mg,Fe,Na,Cl, etc., although of a great importance for life's metabolic processes, form only a small proportion of living matter.

The remaining lithospheric elements although present in relatively small amounts, are of a great value and their presence in the biosphere is of a great consequence in the history of the earth's crust. The biosphere, as has been so definitely shown by W. Vernadsky¹, enters into the majority of geochemical cycles and cannot be neglected in the study of the history of the earth's crust. Nearly all elements, as soon as they reach the zone of weathering, enter into the sphere of activity of the biosphere and are

affected by it in one way or another. Space does not allow one to consider some of the most important cycles, but one may mention here the cycles of iron, manganese, phosphorus, silica, as being the ones which are intimately bound up with the biosphere. Take also the cycle of calcium, which through the agency of the biosphere, becomes intimately bound up with the cycle of carbon. This last cycle is almost entirely determined by the biosphere. Since the beginning of life, probably every atom of carbon (except the juvenile carbon) has passed through the biosphere and some of them probably have passed through it many times.

Diagrammatically the carbon cycle can be represented in the following manner (after Vernadsky)



In the upper zones of the earth's crust CO_2 is distributed as follows

CO_2 in the biosphere	0.64%
" atmosphere	0.007%
" hydrosphere	0.32%
" limestone	98.96%
" coals	0.07%

These figures clearly show the importance of carbonates as a store-room for organogenic carbon (nearly all the limestones are of an organogenic origin), and the small proportion of carbon actually present in the cycle compared with that removed from it. This raises many questions, among

which there is one of vital importance in palaeo-biology: is there any indication that the amount of CO₂ (in atmosphere hydrosphere and biosphere) varied throughout the geological ages? This resolves itself into the question: Whether the output of magmatic CO₂ was always balanced by its intake in the form of carbonates and coal? It is quite possible that after intensive orogenetic periods accompanied by intensive periods of volcanic activity, the amount of free CO₂ markedly increased. This increase would be reflected upon the balance of life which would receive an additional impetus both for development and increase.

What is the origin of life? Unless we accept the element of a miraculous creation we have to suppose that life had a humble beginning on this globe at a certain period of time, and that it has originated from the inorganic. Whether primordial organic matter is still in the process of creation is another question! Theoretically it is possible, but remembering that conditions favouring its formation are also favourable to the higher organised forms of life, the chances of its survival and development are very remote, if not altogether impossible. In any case we may take it that living matter is a dynamic organisation of inanimate matter with the resulting emergent property of "life." Our science is still too young and imperfect to solve the problem of living matter, but it is possible that the progress of organic chemistry, biochemistry and especially the study of colloids, may lead to its solution. The colloidal state is apparently half-way between organic and inorganic. The following table shows this relationship more clearly:

MATTER.

CRYSTALLINE.	COLLOIDAL.	LIVING
Homogeneous	Heterogeneous	Heterogeneous
Static equilibrium	Dynamic equilibrium	Dynamic equilibrium
Growth : addition	Growth : involution	Growth : ingestion (nutrition)
Stable	Metastable	Labile

Certainly we have no doubt that an enormous gap separates living colloids (such as all the organism are) and the purely inorganic colloids, and that a living dog is better than a dead lion, but still there is no reason to suppose that this gap will not be bridged over in the future. This does not mean that the living phenomena are going to be explained in terms of chemistry and physics. Life and mind are always something more than mere chemistry and physics. It is an emergent quality at a higher level of evolution.

Part 2.

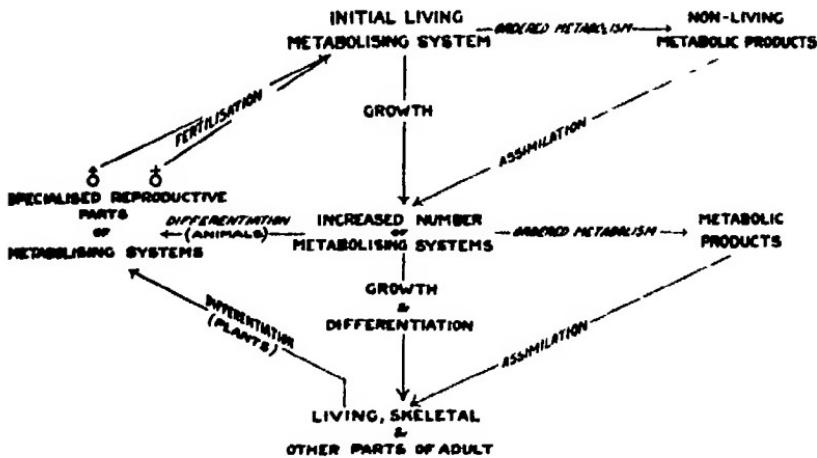
LIMITS OF MAN'S SYNTHETIC POWERS IN THE CHEMISTRY OF LIVING ORGANISMS.

By MEIRION THOMAS, M.A.

Agreement is general among those who have considered biological phenomena critically, that the big gap which exists between the biological and a-biological will, for an indefinite period, necessitate the use of biological terms, as well as physico-chemical terms, in describing the events and processes occurring during the life of an organism. Characteristics of a living organism are the power of using, according to its inherent nature, dissimilar material to increase its substance, so leading to the growth and development of the individual, and the power of reproduction, so yielding similar offspring and maintaining the race to which the organism belongs. Many physico-chemical occurrences, however, are associated with these biological phenomena: for example, definite chemical compounds are continually being formed and incorporated into the living structure by processes which in the sum constitute the metabolism of the organism. But metabolism itself is biological, for, ordered growth and development result from the co-ordinated activities of a given metabolising system i.e., the protoplasm of a given whole living cell. In fact, the characters of an adult organism can be said to be determined by the inherent nature of its initial metabolising system which controls the nature, amount, time and place of forma-

ation of the metabolic products of which the adult is composed.

In the figure given below an attempt has been made to schematise the chemical experience of a typical organism, adequately supplied with all that the environment usefully contributes, so as to bring out the relation between metabolising systems and metabolic products, and so to show the central place occupied by metabolising systems in ontogeny, and by detached parts of them in reproduction.



It is fundamental to the theme of this paper that a clear distinction should be made between metabolising systems—which are living units possessing racial histories and endowed with potentialities for the future—and metabolic products, which are, in themselves, non-living chemical compounds of invariable composition.

Metabolic products can be dealt with by the skilled organic chemist, and since Wöhler's epoch making synthesis of urea in 1828, analyses and syntheses of these products has proceeded with ever increasing rapidity. It is probable that in the not too distant future the organic chemist will have the power to analyse and synthesise all the chemical compounds occurring in plants and animals, and to describe their chemical, physical, and indeed, with some assistance, their physiological properties. This work will obviously

greatly illuminate many fields of biological investigation which are now very dark. We have clearly seen in recent years how great chemical achievements such as those of Emil Fischer in carbohydrate, protein, and purine chemistry and Willstatter in the chemistry of plant pigments, can rapidly correct erroneous views held by biologists, and direct research along new and profitable lines.

Analytical studies of the material nature of metabolising systems* can for our purpose in this paper be classified as of three types (1) Chemical (2) Cytological (3) Biochemical. Chemical analyses really of course only determine the nature of those metabolic products which have become incorporated into the living system. Apparently the protoplasm of all living cells, whether of plants or animals, is always composed of the same kinds of substances, for analysis invariably returns water, inorganic salts in solution, proteins free and combined with nucleic acids and lipoids, carbohydrates, fats, sterols, and phosphatides. There is sufficient potential chemical variation in the protein group, quite apart from that in the other substances, to account for the differences, which must evidently occur, in the material nature of the metabolising systems of all the diverse organisms known in the world. The view that was some time ago advanced by Verworn that these compounds, found on analyses, actually existed in the cell as components of a very large living molecule or biogen implied that by ordinary chemical combination it might be possible for man to produce compounds at the level of molecular complexity and with the arrangement of atoms in the molecule found in biogens, and so deliberately to set about synthesising life. But views such as Verworn's are uncompromisingly opposed at the present day by biologists who hold that the chemical compounds found in cells do not occur there in chemical combination with one another, but are physically aggregated in definite ways, pre-determined by the racial

*Consideration of the metabolising system is definitely limited here to the end of showing that it is not a chemical compound; therefore no mention will be made of bio-physical or of physiological studies.

history of the organism concerned, into microstructures which are also themselves similarly aggregated to form the whole living metabolising system or cell. So, although chemical analysis is essential to throw light on the material nature of protoplasm, it must always be remembered that "on ultimate analysis we can hardly speak at all of living matter in the cell, as we cannot speak of life as associated with any particular type of molecule."

Cytological and biochemical analyses aim at describing the metabolising system in terms of its component micro-structures. The cytologist recognises after close microscopical observation or after micro dissection, nuclei with their chromosomes, plastids, mitochondria, plasmatic membranes and so forth, and the biochemist separates from living cells the micro systems of chemical activity which are called enzymes. Cytologists and biochemists are agreed, as a result of their very different ways of approach of the problem, that the micro-structures of the cell are composed of *mixtures* of chemical compounds. Space does not permit of a critical discussion here, but we yield to the temptation to quote Willstatter who has recently made elaborate but unsuccessful attempts to isolate a pure enzyme. He considers that enzymes are probably mixtures of two or more components having the nature of new chemical compounds owing to the "mutual influence on each other of the electro static and electro magnetic fields of force of the individual components".

It will be remembered that it was stated at the beginning of this paper that the powers of growth and development, and of reproduction are the essential attributes of a living system. For these powers to be shown there must be assembled whole metabolising systems for example, if Amoeba is dissected into two parts, the nucleated part first regenerates the whole organism and then continues its normal life, whereas the non-nucleated part dies. Therefore it is not correct to speak of one particular cytological micro-structure or one particular enzyme as living until it can be proved that it will grow and multiply, and this has not as yet been done for any micro-structure or for any enzyme.

Nor is it enough to consider the living cell as a simple sum of the parts, whether cytological units or enzymes, of which it is composed, for, with the association of these parts there are resultant or emergent qualities depending on the way in which the component parts are put together, and the way in which their activities are co-ordinated. There is much profit to be derived in this connection by comparing the working of a living cell and its parts with that and those of a motor car, or by comparing the co-ordination of events in a living cell with the harmony produced by a large orchestra of many different instruments under the control of a skilled conductor.

It should now be clear that there are two quite distinct problems of synthesis presented to man by living organisms. First, there is the synthesis of metabolic products—definite chemical compounds—which he has attacked with success. Then there is the far bigger problem of the synthesis of the very complex organisation of chemical substances which constitutes the metabolising system. Before synthesis of a *given* living cell, say Amoeba at a time T_1 , can be attempted, it will be necessary to analyse the cell at this time molecule by molecule for this is the only way in which to deal with *organised mixtures*. Such a mode of analysis would demand powers of manipulation which man at present does not possess, but conceivably man may evolve into a creature who will be able to perform this ultra-delicate operation, but if this were to happen he would surely then deserve a new specific name—superman, say. Let superman re-assemble the molecules at a time T_2 , exactly as they were at the time T_1 , then, and only then would the synthesis of the given Amoeba have been effected. It is a debateable point whether the re-integrated Amoeba would be endowed with exactly those powers for itself and its race that it possessed when analysed at T_1 , for it can be argued that there is an immaterial something which is capricious in its attitude towards potential metabolising systems. The author, however, holds as a working hypothesis that life is the natural inevitable result of certain kinds of structure, and therefore, he

thinks that superman's experiments in a-biogenesis would be successful.

The somewhat fantastic ideas put forward in the last paragraph are considered worthy of a place here, as they make clear the limitations, which the author sees, in man's powers to synthesise a *given* form of life from chemical compounds. It is important, however, to distinguish between synthesis in this sense, and the attempts which have been made by many experimenters in the past to bring about spontaneous generation. These attempts are based on arguments which are quite logical, assuming as premises that living forms evolved in Pre-Cambrian waters from non-living chemical compounds by natural processes, and that it is possible to re-assemble in the laboratory all the conditions which led then to the emergence of life. There is no theoretical obstacle to success in producing living forms artificially if the right conditions are by chance employed, and if it is realised that the experiments may have to be very prolonged, but it is most important to appreciate the fact that in such experiments no deliberate attempt is made to produce a *given* form of life: the experiment is set up, and it is hoped that Nature will do the rest! Such haphazard attempts at spontaneous generation, which have frequently been made in the past, are not experiments in 'synthesis, following analysis, of a kind which will satisfy organic chemists, nor need they be considered seriously as yet; for, although claims of success have at various times been made, the overwhelming verdict of those competent to judge is against spontaneous generation and wholly in support of the following conclusions:—

- (1) Every existing metabolising system has come from a pre-existing metabolising system.
- (2) Metabolising systems are not being evolved in the world at the present time.
- (3) Metabolising systems have never been produced artificially.

And the author adds (4) It is inconceivable that man will ever deliberately synthesise a *given* type of metabolising system

I wish to record my thanks to Professor Heslop Harrison F R S for reading the manuscript of this paper, and for offering several helpful criticisms

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ON RHYTHMIC DEPOSITION IN THE YOREDALE SERIES.

By JAMES BROUH, B.Sc.

The term Yoredale Series was applied by John Phillips to the mass of strata, composed mainly of alternating beds of limestone, shale and sandstone, which immediately overlies the Mountain Limestone in North Yorkshire and underlies the Millstone Grit. His sections clearly indicate that the constituent layers do not occur haphazardly, but in a definite order which is repeated time and again throughout the whole succession. In the present paper it will be shown that as these beds are traced northwards from Yorkshire they preserve, not only their essential lithological character, but also their rhythmic arrangement. Further, it is noteworthy that the series shows comparatively little variation in thickness over a lateral distance of one hundred miles or more.

In short, it is suggested that the Yoredale Series is, considering its constituent materials, a formation of singular uniformity in character and of wide distribution, and fully merits recognition as a major subdivision of the British Carboniferous rocks in northern Britain.

The most interesting common character displayed by this series is the phenomenon of rhythmic deposition. This was first noted in the type area, but has been observed also in Durham, Cumberland and Northumberland.

The Rhythmic Unit.

The Yoredale Series may be resolved into major and minor constituents, the latter are more numerous than the former but form only a small portion of the total thickness.

Major Constituents:—Limestone, shale, sandstone.

Minor Constituents:—Fireclay, impure gannister, coal ironstone, chert.

Of the major constituents, limestone is the least bulky. It may, however, form more than one fifth of the total thickness in some sections, the remainder being composed

of sandstone and shale, with the former usually predominating. The order in which these beds occur is definite and fairly constant, the limestone is overlain by a shale, which passes upwards, by alternation into a sandstone. The sandstone may be capped by a fireclay, which may bear an accompanying coal seam. The next bed deposited is a limestone again followed by shale and then sandstone, giving another rhythmic unit.

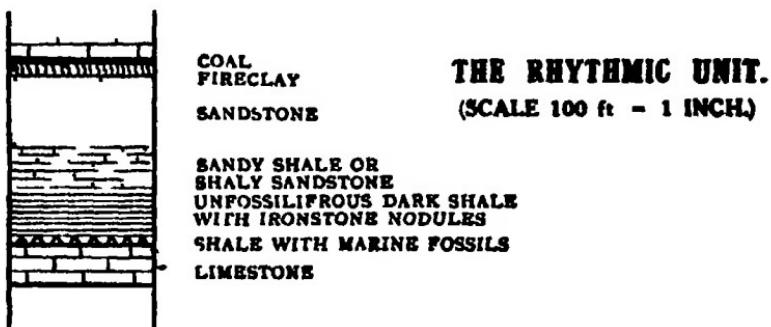


FIG. 1

As there is some difference of opinion regarding the natural beginning and end of the rhythmic unit, a fuller description of its characters will be given below in the discussion of the separate localities.

Wensleydale

As stated above, John Phillips' sections had, at an early period, indicated the rhythmic arrangement of the Yoredale strata in this region. Later, the same phenomenon elicited a short notice from Wheelton Hind,² and quite recently R G S Hudson³ has published an account of these beds, with a very full description and discussion of the rhythm. Following the R A report, the Girvanella band at the base of D₃ is taken as the base of the Yoredales. Thus in the Yorkshire dales the Yoredales consist of approximately 1,200 feet of strata, which is made up of some fourteen rhythmic units which are usually about 100 feet thick, although some units are considerably thinner.

Hudson takes the beginning of a rhythmic unit as the base of the shale, passing up through sandstone and with

limestone at the top He describes a typical rhythmic unit as follows—

" The sequence begins with the shale deposited on an already hardened and sometimes eroded limestone The fauna of the shale is of the " normal shale type " Finally the deposition of the shales was such that no fossils are found, the increased iron content which eventually formed the ironstone nodules may have been the determining factor resulting in such a condition Intercalations of sandstone then occur and eventually the sediment is entirely a sandstone, false bedded and of rapid accumulation Occasionally this sedimentation culminated in emergence and coal seams result at the top, or near the top, of the sandstone Next, the deposition of the sandstone material ceases and clear water follows, in which corals establish themselves on the sandstone surface The lack of sediment and the gradual deepening of the water results in the formation of a limestone, and the establishment of a coral-brachiopod fauna locally replaced by a purely brachiopod assemblage The accumulation of limestone comes to a close in a shallow water lagoon phase of algal growths, and the limestone formation then ceases The sequence is then initiated again by the deposition of a shale sediment "

North Northumberland

The rocky foreshore to the North and South of Beadnell Haven displays a very fine, and almost uninterrupted section of Yoredalian rocks The strata involved lie between the Oxford and the Great limestones and constitute the " Middle limestone group " of the Bernician in the terminology of the Geological Survey⁴ These beds consist of limestones, shales, sandstones, fireclays, impure gannisters and coals, and are equivalent to the lower three quarters of the Yorkshire Yoredales, the Great Limestone being correlated with the Main Limestone and the Oxford Limestone with the Hardraw Scar Limestone⁵

The series displays a rhythm which may be sometimes obscure, but which is never totally lost. Starting at the base the rhythmic unit consists of limestone, fine dark

shale, micaceous shale, shaly sandstone, sandstone and finally fireclay, often capped by a coal seam. The rhythm is best displayed in the lower part of the section.

The limesone was formed, presumably in a clear and shallow sea inhabited by a mixed fauna of corals (usually simple), Crinoids, Brachiopods, Bryozoans, etc., which at times was superseded by a purely brachiopod assemblage, the latter fossils being sometimes very abundant at the top of the limestones. A change in conditions took place and the clear sea was invaded by mud which formed a fine dark shale in which members of the limestone fauna struggled on for a while but were eventually killed off. The shaly marine band thus formed is rarely more than two or three feet thick.

In the rhythmic units of the lower part of the section under discussion the "limestone type" of fauna is succeeded by a definite "shale type", the principal member being *Posidomya becheri*. The nature of the shale gradually changes, it becomes unfossiliferous and to an increasing extent ferruginous, leading to the production of thin seams of nodular ironstone in the upper layers. Coarser material now begins to invade the area, the shales become first micaceous, and later, sandy. In the latter condition they contain, often abundant, but badly preserved plant remains. *Sphenopteris* is occasionally recognisable. With still coarser material being deposited the sandy shale gives way to shaly sandstone, which in turn is superseded by sandstone or grit. Current bedding is a prominent characteristic of the coarser deposits. Sandstone deposition probably culminated in the emergence of sandbanks which were rapidly covered by vegetation to give the fireclays and coal seams which so often mark the top of a rhythmic unit.

At this stage there is a radical and sudden change in conditions, the coal forests are drowned and replaced by an expanse of open water into which little detrital material finds its way. The typical coral-brachiopod fauna again migrates into the area and the accumulation of limestone thus commences, marking the base of the next rhythmic unit.

Mr Hudson takes the base of the shale as the base of the unit and carries on through sandstone and coal to the top of the limestone. In this he is apparently influenced by the presence of limestone conglomerates at the top of certain of the limestones and also by the presence of lagoon phases in them. Such evidences of physical break have not been observed in Northumberland where invariably the marine shales conformably overlying the limestone surface, appear to indicate a gradual passing away of marine conditions.

While it is true that coal and limestone are both to a large extent organic deposits it is clear that these substances were deposited under vastly different physical conditions, indeed, there is as great a difference in deposition as can well exist, for while one is terrestrial the other is purely marine and they mark the two extreme types of deposit found in the series. Such a difference does not exist between limestone and marine shale for they are both marine deposits but they differ in that the shale indicates the oncoming of fine detrital sediment into the area of deposition, the direct result of which is the driving out of clear water loving forms of life, a general impoverishment of the fauna, and hence the cessation of limestone deposition. Arguing on these lines, it seems much more logical to look upon the base of the limestone as the beginning of the rhythmic unit. This horizon does represent a change of some sort, maybe subsidence, for it is quite certain that after limestone deposition, the unit represents a steady silting up.

In the Northumberland area in Yoredale times there seems to have been a fundamental tendency to produce the rhythm, but superimposed upon this were other minor fluctuating movements which have slightly obscured the purely rhythmic sequence.

Thus, occasionally, there seems to have been comparatively prolonged deltaic or estuarine conditions which resulted in thick deposits of sandstone and sandy shale, with plant remains and occasional beds of fireclay, impure gonnister and coal.

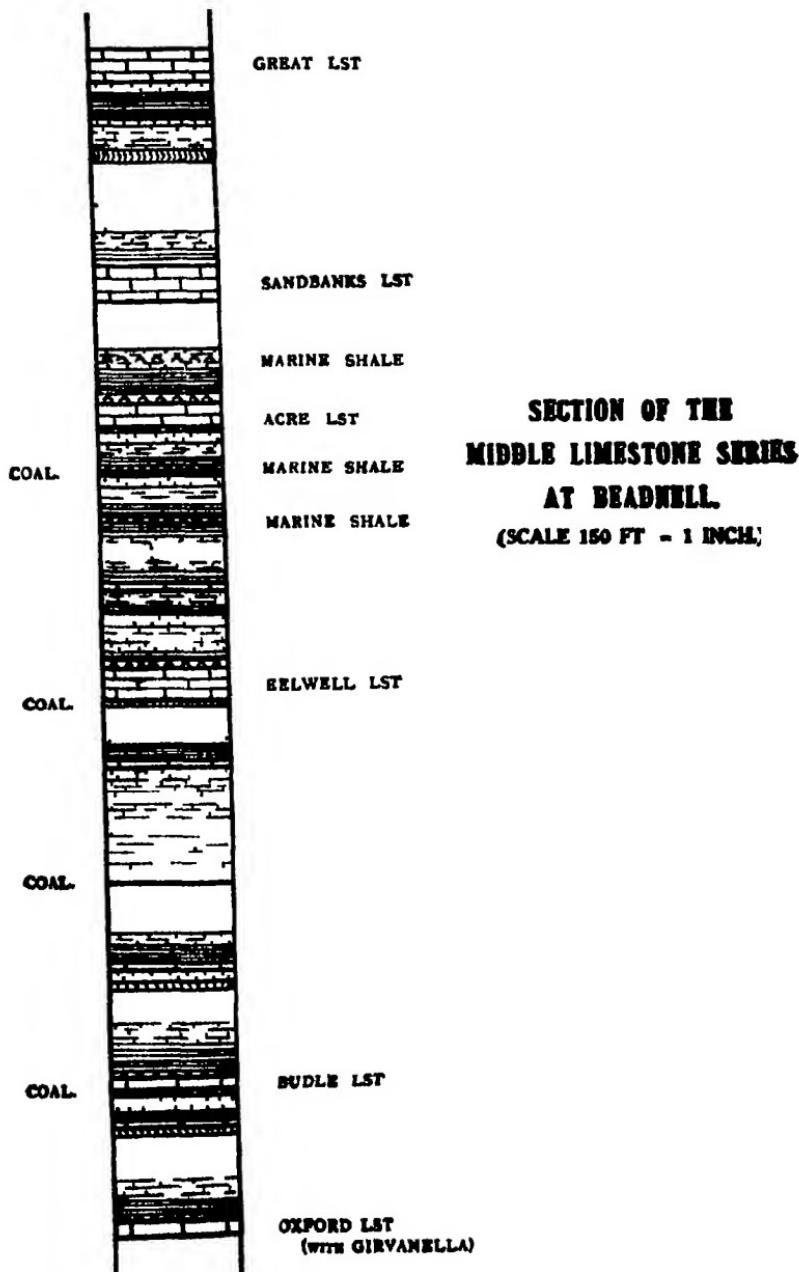


Fig. 2

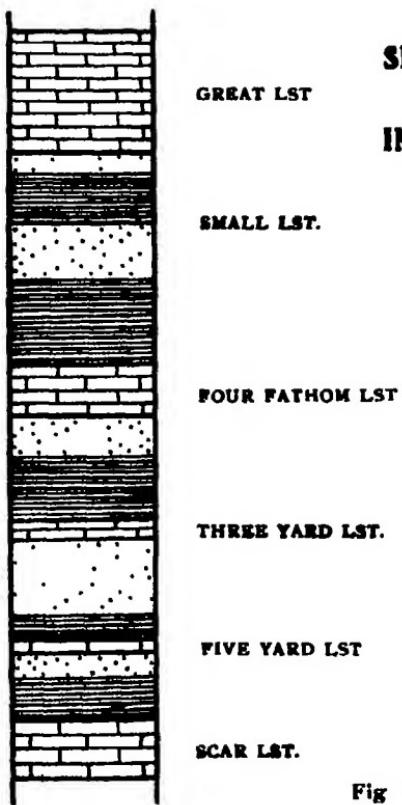
In other cases the rhythm has been interrupted by minor recurrences of marine conditions. This is well demonstrated in the beds below the Acre limestone in the Beadnell section where a thin limestone was deposited and above it fine shale merging into sandy micaceous shale with land plants and finally into a sandstone. So far the rhythm is perfect but the sandstone gives way to sandy shale which is overlain by a thick bed of fine dark shale containing a band with marine fossils a few feet from its base. From the marine band the succession continues normally through dark shale, sandy shale and sandstone to a fireclay with an accompanying coal seam overlain not by a limestone as would be expected but again by a dark shale with marine fossils near the base. After this the succession continues normally through shale and sandstone up to the Acre limestone.

It would appear that these marine bands indicate the presence of two incipient rhythmic units and that conditions at the time were not sufficiently stable to allow the deposition of limestone.

South Northumberland and Cumberland

The rhythmic nature of the Yoredale deposits in this region has not escaped notice. Messrs Trotter and Hollingsworth working in Cumberland remark upon the presence of rhythm in the beds above the Great Limestone and Mr W P Hedley has also observed this phenomenon in the strata between the Great and Harlow Hill limestones in the Tyne valley.

For the beds below the Great Limestone there is less certain information. It is however interesting to notice that in Westgarth Forster's section of the limestone series in the Alston district⁷ all the beds from the Scar limestone to the Great limestone show a regular and repeated sequence of limestone, shale and sandstone. The section is not so detailed as one would desire but it indicates a rhythm in these Yoredale strata which if worked out would probably correspond closely to that observed in Wensleydale and North Northumberland.



**SECTION OF A PART OF
THE YORDALE SERIES
IN THE ALSTON DISTRICT**
after Westgarth Ferster.
(SCALE 100 ft. - 1 INCH.)

Fig. 3.

Scotland.

In many of the sections of the upper and lower limestone series, published by the Geological Survey of Scotland⁸, the beds of limestone, shale and sandstone are seen to preserve the same relations as in the north of England. These deposits are probably equivalent to the Northumberland Yoredales to which they bear a striking similarity. The general uniformity is marred in this region by the interposition of the "Edge Coal Group". This wedge of strata persists into north Northumberland where it is known as the "Lickar Coal Group"; it is here much less important and rapidly thins out to the south.

Cause of the Rhythm

Hudson explained the rhythm by supposing that the Wensleydale Region held balance between an area of limestone deposition to the south and a deltaic area to the North and that this intermediate zone would tend to register physical changes. A succession of slight land uplifts provides the material for successive units. The rhythm is thus explained as a local interdigitation of marine and deltaic material. Now if this were the case in tracing the beds northwards they ought to pass into a mass of deltaic deposits. It is clear from the foregoing descriptions that this is not so we find that the Yoredale beds at Beadnell are quite similar to their Yorkshire equivalents which lie over 100 miles to the south.

The theory involves the suggestion that the particular conditions which produced rhythmic sedimentation were local but from the present evidence it appears that for the North of England at least and at certain periods for Scotland too the conditions were general.

There is one certain and obvious fact the Yoredale Series was deposited in a subsiding area. The subsidence may have been regular or jerky and if the latter the rhythmic deposits may be explained as the successive infillings of a basin which from time to time underwent rapid depression. If the subsidence was regular it is necessary to look for some outside factor which would influence the nature of the sediment being laid down in the Yoredale area. A recurrence of sharp uplift of the land which supplied the detritus would account for the rapid influx of terrigenous sediment which from time to time invaded the limestone sea.

It is also possible to account for the observed rhythm without calling in sudden earth movements in the areas either of supply or of deposition. The products of terrestrial denudation must be transported to the areas of deposition and the obvious transporting agent is water. A change from humidity to aridity in any land area would involve a great diminution in the amount of surface water with a corresponding decrease in the amount of material

transported. If there was a cyclical climatic variation in Yoredale times it is likely that periods of aridity would be represented by the limestones and periods of humidity by the terrigenous sediments and the coal, the area undergoing a slow but steady subsidence all the while.

It is clear that the above paragraphs merely contain an attempt to state the possibilities with regard to the origin of the Yoredale rhythm. Of the alternatives outlined, the third may be looked upon as being too speculative in the present state of our knowledge regarding climatic changes in the past. We do know that climate changes and it is to be remembered that there must always be an intimate connection between climate and sedimentation and further, that a change from humidity to aridity need not involve temperature changes to any great extent a shift in the direction of the prevailing winds would in some cases suffice.

For the present, however it is perhaps as well to return to the more simple factors of uplift and depression, and to regard the Yoredale rhythm as a consequence of uneven earth movements, affecting either the area of supply or of deposition or quite possibly an interaction of movements affecting both.

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- ²Wheelton Hind, *Proc York Geol Soc*, M S , 1902, Vol XIV , Part III
- ³R G S Hudson *Proc York Geol Soc*, 1923 24 Vol XX , Part I
- *The accompanying section of the Beadnell foreshore was constructed in 1926 and the limestones were named from the new series Geological Survey maps of North Northumberland. In 1927, Mr G A Burnett's detailed description of the Beadnell shore section appeared in the Geological Survey publication, "The Geology of Belford, Holy Island and the Farne Islands"

- ⁵W Gunn *Trans Edin Geol Soc* 1899 Vol VII Part IV
- ⁶F M Trotter and S E Hollingsworth *Summary of Progress* 1926 Appendix II
- ⁷A Treatise on a section of the strata from Newcastle on Tyne to the mountain of Cross Fell in Cumberland (1821)
- ⁸Geology of the Glasgow District 1921 *Mem Geol Survey and others*

NORTHUMBERLAND DIALECT RESEARCH

FIRST REPORT

By HAROLD ORTON

November last saw the inauguration of the Armstrong College Survey of the vernacular forms of speech used in Northumberland. The scheme owes its inception very largely to a number of interested Northumbrians who have provided sufficient monies to cover the initial expenses of the investigations. Work upon the task has been carried on by the English Department of the College continuously since that time. Progress has been and must be, somewhat slow owing to the professional duties of those engaged in the Survey. But a stage has now been reached when a halt in operations could with advantage be made in order to review what has already been accomplished and to consider how best to proceed in the future.

A fair amount of attention has been devoted in the past to the dialects of Northumberland, notably by the late Oliver Heslop whose *Glossary of Northumbrian Words* is the standard work on the provincial vocabulary of this county. But Heslop was also deeply interested in the various limits of the dialect groups, and the map which he plotted and published in his great work has already proved its value for our purposes. We deplore the fact that our labours cannot now receive the help, guidance and encouragement which would surely have been forthcoming from so erudite an authority as he obviously was. The grammar of the dialect spoken on Tyneside has also been explored by the Rev J E Hull, and his researches, printed in the *Vasculum* for 1922, form a valuable contribution to this department of learning. The sound systems of our local forms of speech have also been treated by Ellis and Wright, but no-one will deny that a satisfactory phonological study, or rather series of studies, of the Northumbrian dialects has yet to see the light of day. It is with this particular aspect of local dialect investigation that our English Department is primarily concerned.

One of the principal aims of the Survey is the assembly of a large number of mechanical recordings of the Northumbrian dialects. These records will be deposited in the College Library. The interest of such a collection to future generations, as well as its value to English philological science, need not be discussed in this place. That this task be carried out as speedily as possible is essential. Nevertheless there are certain risks attendant upon precipitate haste. The making of a satisfactory record requires a vast amount of preparatory work. Our attitude to dialect as spoken today must be one of caution. The current vernaculars in this county are not necessarily pure. It is indeed beyond question that they have been corrupted to a large extent by extraneous influences, and that they have absorbed a great deal from Standard English in the course of the last four or five centuries. The correctness of this attitude is vouched for by all our authorities, it is confirmed by the researches of our dialect specialists, and also by our own limited observations in this neighbourhood. Ability to sift the genuine native elements from the hybrid forms of speech now employed is one of the essential qualifications of twentieth century dialectologists, and any competence in this respect presupposes a knowledge of the history of the sounds not only of the particular dialect under examination but also of its cognates. One of the more prominent results of our investigations up to date is, that we may now fairly claim to be able to distinguish between what is native to Northumberland and what is derived from external sources. This is certainly not less in importance than the information that has so far been collected and card indexed. How "impure" local dialect is, may be gathered from the following. Many speakers in our area habitually use exactly the same vowel in the words *bone*, *both*, *stone* etc., viz [ə] (*mid front slack round*, though lowered and retracted), as they do in *close* adj., *coat*, *nose* etc. Or, to put it another way, both ME ā and ī, (*slack*) may give rise to present-day [o]. But these [ə]-forms are, from historical reasons, most certainly of alien origin—in all probability from Early Standard English—and

yet they may be considered just as typical of current Northumbrian as those pronunciations exhibiting the genuine representatives of old *a* and *ō*, viz [i ɪ= (?) ia] and [uɪ] respectively. Again, the traditional forms of words like *old*, *cold*, *hold* etc manifest a long vowel of the [ā] type (*fully open front slack unrounded*), in other districts they contain the above mentioned [ō] whilst the etymological *l* has normally ceased to be pronounced. Alternative forms with [ɔɪl] however, are widely prevalent in our area, as elsewhere in the North of England. These may also be shown to have been borrowed in the first place from Early Standard. One additional instance will suffice. Northumbrians frequently employ the same vowel in words of the type *board*, *corn*, *horn* etc, viz [ɔ] (*low-back tense round*) as in words like *bird*, *third* etc. In neither group is the sound in question the true rative development: the former class contain, when normal, the diphthong [uo] (*high back tense round*, lowered + *mid flat slack* lowered towards *low back* position), whereas the latter exhibit [eo] (first element being *mid front tense*). Diphthongal pronunciations of these kinds, though still extant, are obsolescent. The [ɔ] forms are similarly of non-native origin. It will thus be clear that if our gramophone records are to give a faithful picture of really genuine dialect, not only must the selection of the speaker be made very carefully, but much caution must also be exercised in the choice of the material to be dictated. Incidentally no decision has yet been made as to whether this material shall represent the hybrid vernacular now employed by most provincials or whether it shall first be weeded of its alien elements. We venture to believe that it is still possible to record forms of local dialect that preserve their traditional phonological characteristics without being archaic, and, further, that if our recordings are to be of the greatest possible service to students of English philology, some reconstruction of the dialect specimens in the way suggested will be essential.

One other topic may be conveniently discussed here, namely the subject matter of the proposed gramophone records. Recording of dialect for scientific purposes is of

course no new thing. The nature of the existing records varies considerably, however. German workers in this field—and the Germans some few years ago took advantage of a wonderful opportunity to make a comprehensive series of dialect records in the prisoner of war internment camps—seem to have preferred biblical matter, as e.g. the Parable of the Prodigal Son. Other students have expressed themselves in favour of proverbs, trite sayings, homely similes and verses in dialect. But whatever material be chosen it is imperative that every assistance be given to the speaker to enable him to reproduce his normal intonation. Here in Northumberland where in ordinary conversation the musical melody of the sentence is one of the most striking features of the different forms of provincial speech, one must be particularly vigilant in this matter. We are therefore inclined to the opinion that formal material such as extracts from the Bible and dialect poems should be rigorously excluded. Although the final decision has yet to be made we believe that a satisfactory record would be one that embodied a number of carefully selected words illustrating the historical problems of the particular dialect concerned, a few proverbs, similes and quaint sayings, in addition to a racy story or perhaps two. Possibly some reader of these notes would care to furnish material of this kind. Needless to say, suggestions would be cordially welcomed by the Survey. Any such communications might be directed to the present writer at the College.

As regards the commercial aspect of the proposed gramophone records, our tentative efforts to interest manufacturers have so far been unavailing. As a last resort, however, it may prove necessary to call in the aid of some foreign firm or other. It is understood that the same thing has been done elsewhere in these islands, namely at Cork, where the University authorities empowered a German recording company to carry out work similar to that which it is desired to have done in this county.

We may now pass on to the more tangible results of our inquiries up to date. Work is proceeding on the dialects

spoken in three different areas in the South of the county, namely those converging on Newbrough nr Hexham), Capheaton and Bellingham respectively and already a total of between 1400 and 1500 pronunciations have been noted, about a thousand of which have been card indexed. We would take this opportunity of acknowledging the voluntary and efficient help rendered by Mr Bowman and Mr Curry members of our Second Year Honours Class who have been good enough to insert on the cards the etymologies of some hundreds of these dialect forms. The material in our possession comprises, in addition fairly detailed descriptions in scientific terminology of the sound systems of Newbrough and Capheaton. A phonetic alphabet is of course being employed in which to register the information for it is only by some such means as this that students of dialect both at home and abroad will be enabled to gain any precise notion of Northumbrian sounds without going to the extent of spending many months in the county. The orthographical systems used by many writers of dialect though often fairly intelligible to persons familiar with the locality are wholly inadequate for scientific purposes and moreover, often productive of the greatest confusion. Consider for a moment the spellings that are often intended to indicate a certain Northumberland pronunciation of the word *book*. Readers will probably have noticed such variants as *buke*, *buk* *buyk* *beuk* *bewk* *byuk*. Spellings of this kind suggest to the English phonetician a fairly extensive range of pronunciations. But foreign students of English dialects—and the work of foreign scholars in this connexion ranks with the best—are obviously in a much worse plight. Such bewildering combinations of letters must, indeed be for them a positive nightmare. It was in fact, many years ago that dialectologists abandoned the use of ordinary spelling for the recording the dialect information that they wished to give to the world.

The material in our collections will have to be confirmed, later on by observations in the particular districts, because all of it, except in the case of Bellingham, has been

supplied by individual helpers Our informants are, for Newbrough, Mr Wm Nixon, pumpman, of Gateshead, and a native of Newbrough, and for Capheaton, Mr Ralph Carr, L D S, of Newcastle As regards Bellingham, the present writer has spent five days researching into the dialect, or better, perhaps, dialects spoken there But since then, Mr J Upton Smith L D S, of Gosforth has kindly offered his assistance, and placed his detailed knowledge of this dialect at our disposal We would here place on record our deep appreciation of the eminent services already given by these three helpers, and we tender them our thanks How fortunate is the Survey in securing such competent assistance in this immediate neighbourhood, will be realized at once With their co operation the whole of the spade work upon the three dialects in question may be done in Newcastle itself, with the consequent saving of a considerable amount of time and money Perhaps these notes will pass into the hands of some who are in a position to afford similar aid for other districts If so, it is earnestly hoped that such readers will be good enough to allow us the benefit of their stores of knowledge To be enabled to begin our investigations in the field knowing pretty well what to expect, would lighten our task immeasurably It may perhaps be added that we are looking forward eagerly to a not distant future when some of the students of the Department will be fully qualified to undertake the scientific exploration of the vernaculars of both Northumberland and Durham, or for that matter, of any other county in the kingdom The organisation of such a school of dialectologists would be an event without parallel in this country In the meantime much valuable work can, and, it is hoped, will be done by our undergraduates, even with their present limited opportunities, in the verification and enlargement of the material already assembled

The dialects so far examined appear to exhibit certain well marked distinguishing peculiarities, to which some space may be allotted here Under the circumstances, nevertheless, it would be well to point out that these remarks should be considered provisional, and that they may

require modification in the light of the results of further investigation. One of the most characteristic features of the Newbrough dialect is undoubtedly the levelling, under normal conditions, of ME *al* followed by a consonant and ME *au* under a rounded vowel, viz long [ə] (*mid-front-slack-round*, lowered and retracted). Hence words like *old*, *cold*, *hold* etc nowadays manifest a vowel which is identical with that of *claw*, *jaw*, *law* etc. This rounded vowel is, in the opinion of the present writer, the continuation of an earlier [ɑ̄] (*mid-back-slack*), and to judge from the spelling *Hoatewhistle*, 1655, for the place-name Haltwhistle (Nhb., first element is OFr *haut* 'high') noted by Professor Mawer in his "Place-Names of Northumberland and Durham", p. 100, the ME diphthong *au*, and together with it ME *al* before a consonant, had become modified to a vowel of the type [ə] (*mid-back-slack-round*) by the middle of the seventeenth century at latest. To continue, Newbrough differs entirely in respect of this development from Capheaton, where ME *au* and *al* are now represented by [ɑ̄] (*fully-open front-slack*). On the other hand in Bellingham, curiously enough, we find both [ə] and [ɑ̄], and we are unable at the moment to say which is really indigenous and which is of external provenience. The writer has actually heard both types used in ordinary conversation by one and the same speaker within the course of two or three minutes.

Again, in Newbrough ME ā (as e.g. in *bone*, *both*, *most*, *stone* etc) and ME ō¹ (as in *book*, *moon*, *nook*, *tool* etc) give rise to the same sound in a medial position, viz the diphthong (ie) (*high-front tense lowered + mid-front-tense retracted towards the mid-flat*). Nevertheless in Capheaton they are still quite distinct, old ā being represented by [ɪə] (*high-front tense lowered + mid-flat-slack*) and ō, by [ɪə] (*high front slack + mid-flat-tense-round*). The regular Bellingham correspondences of the ME sounds in question are as yet undetermined, although our observations suggest that here too much confusion exists. Other points of difference between the three dialects have been noted, but it would be unnecessary to go more deeply into the matter in this place, and, besides, enough has been

said to indicate the methods that are being pursued in our attempt to classify the local vernaculars

As regards the history of the Northumbrian dialects—and bound up with it is the history of the population of the county—we regret that any comprehensive treatment of the subject at our hands must be postponed for some time owing to the urgency of the more immediate purpose, the collection of the raw material. This is all the more to be deplored since, in addition to the likelihood that it will provide a number of fascinating problems, this field of study remains unexplored as far as Northumberland is concerned. It may be of interest to note here that the historical side of English dialectology is nowadays based largely on the early spellings of local place names and the deviations from the traditional orthography that are to be found in the documents, both public and private, connected with the particular region under examination. Students of the Northern dialects have access to a veritable mine of information in this respect in the records published by the Surtees Society.

Finally a word as to the reception accorded to our work. In the course of our studies we have come into contact with men and women drawn from many grades of society and have talked e.g. with roadmen, blacksmiths, joiners, farm labourers, window cleaners, grocers and various shopkeepers, as also the heterogeneous types in a football crowd, and everywhere the subject has always evoked interest. It would appear as if the mere mention of Northumbrian Dialect is one of the quickest ways of gaining a whole host of good friends in this county. In this sympathetic reception of the general public, as also for the generous measure of financial support already given by certain of our well-wishers, the members of the Survey have cause for the deepest satisfaction.

The following specimens from our cards will show at a glance what is being collected and the form of record

Newbrough		Capheaton		Bellingham
[əd]	old	[əd]	old	[ə] + [əd] old
+ [ɔuld] (early loan > St E)		+ [ɔuld] (do)		+ [ɔuld] (do)
+ [ɔld] (late loan > St E)		+ [ɔld] (do)		+ [ɔld] (do)
ME <i>ald</i> > Angl <i>ald</i>		do		do

Newbrough		Capheaton		Bellingham
[blek]	book	[blek]	book	[blek] + [blek] book
ME <i>bōk</i> > OE <i>bōk</i>		do		do

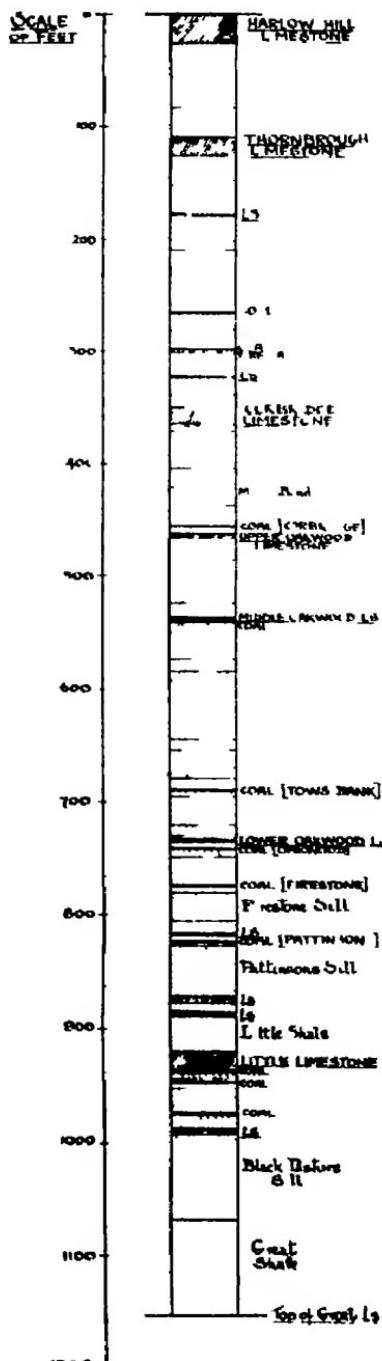
THE SEQUENCE OF THE UPPER LIMESTONE GROUP
BETWEEN CORBRIDGE AND BELSAY

By W PERCY HEDLEY and S TEMPLE WAITE, B Sc

The district under consideration has long been recognised as one of considerable interest, and has often attracted the attention of geologists. Owing to the sequence not being correctly understood, the results have never been entirely satisfactory. Through the kindness of Mr Bates of the Mickley Coal Company, the writers have had placed at their disposal, the record of a recent boring put down by that Company at Dilston Bridge, just outside the limits of the district taken for this paper. This taken in combination with the sequence established by Trotter and Hollingsworth in the Brampton District¹ has gone a long way towards clearing up many hitherto unsolved problems in this district.

Amongst previous workers in the district, Professor G A Lebour and Dr Stanley Smith have each done a great deal. The former's paper² was the first step, and the latter, who acted as Secretary to the Committee appointed in 1912 by the North of England Institute of Mining and Mechanical Engineers to report on the Carboniferous Limestone Formation, with special reference to its Coal Resources, carried the work still further.

The boundaries of the district under consideration are Dere Street (Watling Street) on the West, the River Blyth on the North and the Tyne on the South. The upper Limestone Group has been taken as the strata between the Great Limestone and the Harlow Hill Limestone. This upper limit is the last calcareous bed which can be traced continuously across the district, but the writers do not wish to imply that this bed is necessarily the dividing line between the Limestone Group and the Millstone Grit. The boundary between these two divisions of the Carboniferous has been somewhat arbitrary, 'being determined simply for convenience by the outcrop of the highest calcareous member of the lower set of beds'.



THE SEQUENCE

(A list of the borings referred to will be found in the Appendix)

The Great Limestone is so well defined by its great thickness that it becomes a prominent feature of the landscape and has been worked in many places along its outcrop

Great Shale Immediately overlying the Great Limestone is a thick bed of shale comparable with the Great Shale of the Alston District. No borings in this district pass through it but at Fallowfield two borings record it as 86.6" (B & S 818) and 89.8" (B & S 836) thick

Black Pasture Sill Above the Great Shale is a massive building sandstone the Black Pasture stone of the North Tyne Borings at Fallowfield proved it as 62.0" (B & S 838) and 89.7" (B & S 836) thick. This sill forms Uggoe Hill and Kearsley Fell near Ingoe. Near Whittington it has been quarried at Pikehill and Sharpley Quarries.

Snope Burn Marine Band Between the Black Pasture Sill and the Main Coal of the Little Limestone Coals are beds of shale and sandstone, and in part of the district at least one or more limestones of the horizon of the Snope Burn Marine Band of the Brampton Gilsland section. They may perhaps be the same as the thin limestone or limestones exposed in the bed of the South Tyne below Allerwash and in the bed of the Silly Burn north-east of Haydon Bridge. B & S 838 at Fallowfield has the following strata —

MAIN COAL

Shale	6 4"	
Sandstone	6 9"	
Shale	1 0"	
		14 1"
LIMESTONE		12 0"
Sandstone		38 0"
LIMESTONE		9 0"
Shale		5 0"
		<hr/>
Blk Pasture Sill		78 1"

The limestones are absent in B & S. 836 at Fallowfield, and at Boghall, near the northern boundary of the district under consideration, B & S. 1243 has the following section below the ' Main Coal '—

MAIN COAL.

Shale	...	...	...	1' 2"
Sandstone	...	...	...	2' 0"
Sa. or Whin	...	..	..	2' 0"
Limestone or Whin	...	...	..	1' 0"
Sandstone	...	...	...	2' 0"
Whin	...	...	...	0' 7"
				—
				8' 9"

NOTE.—" Whin " in borer's records denotes any hard stone, and in many cases can be shewn to be limestone.

Little Limestone Coals. The coals underlying the Little Limestone have been worked both by drifts and shafts along almost the whole line of outcrop in the district. The late Professor G.A. Lebour's work on 'The Little Limestone and its Accompanying Coal' leaves very little further to be said on these beds, and it has been considered by the writers only necessary in this paper to give the following table of strata recorded by borings at different places in the district:—

B. & S. 119.

Little Limestone.	
Sh. 0' 4"	
COAL 0' 5"	
Sa. 6' 6"	
Sh. 3' 1"	
	—
UPPER COAL	10' 4"
Sh. 0' 3"	
COAL 0' 3"	
Sh. 1' 5"	
	—
MAIN COAL	10' 8"
	—
MAIN COAL	3' 0"
	—

B. & S. 250.

Little Limestone.	
Sa. 12' 0"	
Sh. 12' 0"	
	—
MAIN COAL	24' 0"
	—
	3' 8"
	—
UPPER COAL	27' 8"
	—

B. & S. 251.

Little Limestone.	
Sa. 45' 7"	
MAIN COAL 3' 8"	
	—
24' 3"	
	—
49' 3"	

B. & S. 286.

Little Limestone

Sh.	...	1' 6"
Sa.	...	4' 6"
Sh.	...	6' 0"
	—	12' 0"
UPPER COAL		0' 4"
Sh.	...	0' 3"
Sa.	...	14' 3"
Sh.	...	8' 9"
	—	23' 3"
MAIN COAL		2' 7"
	—	38' 2"

Grace Pit, Kirkheaton.

Little Limestone

Sa.	...	5' 0"
Sh.	...	3' 0"
	—	8' 0"
UPPER COAL		0' 5"
Fireclay	...	3' 7"
Sh.	...	7' 0"
Sa.	...	27' 4"
	—	37' 11"
MAIN COAL		3' 8"
	—	50' 0"

B. & S. 287.

Little Limestone

UPPER COAL		1' 0"
Sh.	...	4' 0"
Sa.	...	5' 0"
Sh.	...	1' 6"
	—	10' 6"
MAIN COAL		3' 2"
	—	14' 8"

B. & S. 1249.

Little Limestone

Sh.	...	7' 0"
UPPER COAL		1' 0"
Sa.	...	32' 7"
Sh.	...	1' 4"
	—	33' 11"
MAIN COAL		2' 6"
	—	44' 5"

Fenwick Pit, No. 1.

Little Limestone

Sh.	...	1' 0"
Sa.	...	19' 0"
Sh.	...	3' 0"
	—	23' 0"
MAIN COAL		3' 0"
	—	26' 0"

Fenwick Pit, No. 2.

Little Limestone

Sh.	...	6' 0"
Sa.	...	15' 0"
	—	21' 0"
MAIN COAL		2' 2"
	—	23' 2"

Little Limestone. The coal seams underlying the Little Limestone have given the limestone more prominence than it otherwise would have gained. The limestone is always divided into two or more posts by beds of shale, thus

rendering it comparatively useless for lime burning or road metal. At Ingoe however it has been worked to some extent. The line of outcrop can be traced through most of the district only by the underlying coals. Between Little Whittington and Fenwick surface deposits obscure the strike, and the position of the outcrop near Matfen is rather doubtful. A borehole put down at Matfen Tillery reached the limestone through 1716 ft of strata. Borings at Fenwick record the limestone as 139 ft (No 1 Pit) and 116 ft (No 2 Pit). Further north in the Kirkheaton district the limestone varies from 100 ft (B & S 20) to 220 ft (B & S 1249). B & S 119 shews clearly how the limestone posts are divided by calcareous shales. This section is given as follows —

Sa and Whin	5 0"
Sa and Sh	3 6"
LIMESTONE	1 6
Sa	2 2"
LIMESTONE	4 2"
	—
	16 4"
	—

Little Shale. Overlying the Little Limestone is a thick bed of shale which in part of the district contains girdles of ironstone and limestone. These girdles are most prominent in the Corbridge area and are not present near Kirkheaton. Borings through the Little Shale include the following —

MATFEN TILLERY

Pattinson's Sill	
Limestone	6 0
Shale	6 0"
Limestone	0 6"
Shale	32 0"

B & S 119

Pattinson's Sill	
Dark grey metal with metalstone & iron- stone girdles	38 6"
Strong grey post	1 6"
Little Limestone	

FENWICK PIT NO 1

Pattinson's Sill	
Brown and Metal Stone with lime stone girdles	26 0"
Little Limestone	

At the Grace Pit, Kirkheaton Colliery, the Little Shale is 326', at Fenwick No 2 Pit 280' at Boghall Colliery (B & S 250) '60

Pattinsons Sill The massive grit which forms Ingoe North Crag is equivalent to Pattinsons Sill of the Alston Mining District. The terms Ingoe Grit and Shaftoe Grit have been applied not only to this sill in itself but inclusive of other thick sandstones and grits lying higher in the series.

B & S 119

Strongish grey post	1 0
Strong whitish yellow post	3 3"
Strong white grey post	3 0"
Yellowish brown post	4 0
Grey post	6 6"
Dark grey post with thin beds of white post	18 0"
Strong whitish grey post	7 7"
Little Shale	
	<hr/>
	43 4"

Pattinsons Sill is thicker than this in the western portion of the district. In a recent boring at Dilston Bridge it was proved 1046' thick but this thickness is abnormal. Borings near Fallowfield (outside the district) record it as about 50' thick.

Pattinson and Venture Marine Bands: Between Pattinsons Sill and the next thick sandstone the Firestone Sill above it, are alternating beds of thin sandstones and shales and occasionally a thin limestone. This marine band represents a similar horizon to the Pattinson and Venture Marine Bands of N E Cumberland. The strata of this section cannot be seen on the surface but is proved in borings. It seems to occupy the gap at Ingoe between the North Crag and the line of crags just north from Sandyway Heads farmhouse. Between Pattinsons Sill and the Firestone Sill we have the following —

B & S 119

Firestone Sill

Sa and Whin
Shale

6 6" Shale
2' 0" Sandstone

B & S 120

Firestone Sill

8' 0"
4' .0"

Sandstone	1' 4"	LIMESTONE	1 11"
Sa. and Whin	0' 8"	Sh. and Sa	5' 0"
Shale	0' 8"	Coal	0' 9"
		Shale	2' 0"

Pattinsons Sill

Pattinsons Sill.

A borehole west of Acomb (outside the district) records "Whin" 27" immediately above Pattinsons Sill, and a borehole from the drift SW of Acomb shews a limestone 26" at the same horizon.

Firestone Sill This sandstone forms the high ground east of Ingoe village on which the farmhouse of Sandyway Heads stands. It is usually about 20' to 30' thick. Milk Hill, north of Matfen is probably of this horizon. B & S 119 records the sill as 29'6" thick, divided into two posts 10'0" and 17'4" by 22" of shale.

Firestone Band and Oakwood Coal Above the Firestone Sill and between it and the Lower Oakwood limestone are shales, ironstone and thin coals which should include the Firestone Marine Band of NW Cumberland (a coal-calcareous horizon). No borings actually in the district pass through all this strata, but at Fallowfield the section in B & S 838 is as follows —

Lower Oakwood Limestone.

Sandstone and girdles . . .	4' 6"
COAL (Oakwood Seam) . . .	1' 6"
Sandstone	7' 2"
Shale and Ironstone . . .	25' 0"
Sandstone	3' 0"
Shale	3' 6"
COAL (Firestone Seam) . . .	0' 4"
Shale	5' 0"
	50' 0"

Firestone Sill.

The Oakwood or Clarewood Coal was at one time worked in several places in the district. It has sometimes been confused with the Little Limestone Coal. The coal varies from 9" to 18" and is usually separated from the Lower Oakwood limestone above it by a bed of blue shale 4' to 8' in thickness. Between Halton and Clarewood the

coal was at one time worked from several drifts and shafts
Sections here include the following —

Pit W of footpath from Halton to the Roman Station		Drift from the surface at Halton Colliery (B & S 2730)	
Surface Deposits	24 0	LIMESTONE	2 0"
Blue Shale	7 6	Blue Shale	0 2"
COAL (Oakwood)	1 6	Grey Beds	1 0"
		Blue Shale	8 0"
	33 0	COAL (Oakwood)	1 4"
<hr/>			
A deeper pit to the north of North Farm			12 6"
<hr/>			
Surface Deposits	5 6		
Strata	42 5		
LIMESTONE	2 2		
Grey Beds	5 0		
Blue Plate	3 0"		
Fireclay	1 0		
COAL (Oakwood)	1 5		
<hr/>			
	60 6		

The working from Halton Colliery extended about a mile and a half in a north easterly direction

Lower Oakwood Limestone This limestone though rarely more than 3 thick is a very constant bed It can be seen in the bed of the Fenwick Burn, south east of Moralees This limestone is the Felltop of the Alston District

Tows Bank Band Between the Lower and Middle Oakwood Limestones is a thickness of about 200 ft which is made up by a thick shale a thin coal, and three massive sandstones divided by shales The sandstone forms the high ridge running across Stagshaw Common and Carr Hill it also forms the crag south east from Belsay Barns B & S 106 at this latter place shews the following section.

Sandstone	5 3"
Shale	12 0"
Sandstone	5 6"
COAL (Tows Bank)	0 6"
Sandstone	12 0"
Shale	16 9"
<hr/>	
	52 0"

The complete section between the Lower and Middle Oakwood limestones is not shewn in any boring in the district, but the recent boring at Dilston Bridge proves a section which is probably applicable to the whole district under consideration:—

DILSTON BRIDGE.	BOREHOLE near HALTON.
Middle Oakwood L'st.	
Sandstone 1' 0"	Sandstone 52' 0"
COAL (Middle Oakw'd) 0' 6"	COAL (Tows Bank) 0' 9"
Sandstone 34' 3"	Shale 23' 9"
Thin Sa's. & Sh's 11' 6"	Sandstone 5' 10"
Sandstone 58' 2"	Shale 2' 0"
Thin Sa's. & Sh's. 12' 1"	Sandstone 8' 8"
Sandstone 27' 3"	
Shale and Coal (Tows Bank) 13' 2"	
Shale 37' 5"	
Sandstone 11' 9"	
Shale 2' 4"	
	93' 0"

	211' 5"

Lower Oakwood L'st.

Middle Oakwood Limestone.—Another coal-calcareous horizon. The limestone occurs on the surface in the bed of the stream between Wester Heugh and Fenwick. It seems to be represented in B.&S.999 at Aydon Eastside by 'whin' 88'6" below the Upper Oakwood limestone. The underlying coal outcrops on Wallridge Moor and near Dean House.

Upper Oakwood Limestone. About 70' of alternating sandstones and shales separate the Middle Oakwood and Upper Oakwood limestones. B.&S.999 at Aydon Eastside records the limestone at a depth of 53'3", and 4'0" thick.

Corbridge Coal. The coal which was at one time worked at Dean side and at Aydon White House lies above the Upper Oakwood limestone. The shaft section at Dean-side (B & S 544) and a boring at Corbridge Pottery are as follows:—

DEANSIDE B. & S. 544.

		CORBRIDGE POTTERY. Corbridge Limestone.
Sandstone	... ...	4' 0"
Shale	... ...	16' 0"
Hard bluish rock	2'0"	
Hard brown rock	8'0"	
Hard grit	4'0"	
Hard grit with lime- stone shells	4'0"	
		— 14' 0"
Shale	... ...	5' 4"
Sandstone	... ...	3' 0"
Ironstone & Shale	..	3' 0"
Coal	... ..	0' 5"
Fireclay	..	2' 6"
Shale	... ..	1' 4"
COAL (Corbridge)	...	1' 5"
Shale	... ..	4' 0"
		— 55' 0"

Near Belsay Burnside, B.&S 113 records the section above the Corbridge Coal thus:—

Sandstone	...	...	26' 6"
Shale	..	...	0' 6"
Sa. and Whin	...	...	6' 0"
Sh. and Whin	...	...	47' 0"
Limestone	...	...	2' 6"
Shale	...	...	8' 0"
COAL (Corbridge?)	...	...	1' 3"
Shale	...	...	0' 4"
			— 92' 1"

Corbridge Limestone. This limestone has been extensively quarried for lime-burning on the outskirts of Corbridge—behind Croft House and at Deadridge. At the latter place it can be seen with a thick bed of sandstone overlying it; and a valuable bed of fireclay immediately below the limestone is so extensive that the Corbridge Potteries for the manufacture of pipes and troughs from this clay have been a thriving industry for some considerable time. The next outcrop of the limestone to the north-east occurs at the east end of Aydon village where the extent of the old workings shews that the limekilns here must

have been in use at an early date, at the present time the quarries are almost entirely overgrown. Beyond Aydon the line of strike is interrupted by two or more faults. The limestone has been worked at Aydon Eastside, near Greenleighton and at Kiphill. Between here and Nesbit Kiln House the limestone lies under a thick deposit of boulder clay, but from Nesbit Kiln House to the River Pont the line of strike can be very easily traced by the course of old quarry workings. At Hawkwell it has been so much quarried for lime-burning that the limestone has been entirely removed from an area of over ten acres. At one time Hawkwell lime was considered about the best produced in this part of the county. North of the Pont the limestone outcrops at Mainsbank and Heugh, and can be seen in the bed of the Black Heddon Burn some distance above the bridge. At Bygate and Belsay very extensive old workings can be seen.

The Corbridge Limestone is characterised in this district by the absence of corals such as distinguish the Thornbrough and Harlow Hill limestones, and by the quantity of *Buxtonia scabriculus* (Mart.)

The beds between the Corbridge and Thornbrough limestones cannot be seen in any stream section in the district, nor does any one boring cover the complete section. Taking the borings put down at Stob Hill and Richmond Hill, near Stamfordham, and supplemented by recent borings at Dilston Bridge and Craneshaugh (just outside the district) we can, however, obtain a fairly complete section:—

DILSTON BRIDGE.			CRANESHAUGH.		
Sa.	... ..	1' 2"	Sa.	... ..	16' 11"
Sh.	... ..	7' 7"	Sh. with 5" Coal	... ..	57' 8"
Sa. with Sh. bands	10' 8"		Sa. and Sh.	... ..	22' 3"
Sh. with 6" Coal	46' 5"		Sh. with 3" Coal and		
Sa.	... ..	5' 0"	Fireclay	... ..	15' 0"
Sh. with 3" Coal	19' 6"		Sa.	... ..	27' 8"
Sa.	... ..	13' 2"	LIMESTONE	... ..	0' 9"
Sh.	... ..	8' 10"	Sa. and Sh.	... ..	17' 11"
Sa.	... ..	11' 3"	Sh. ... ..	... ..	15' 6"
Sh.	... ..	4' 6"	Corbridge L'st.		
Corbridge L'st.					

STOB HILL.
Thornbrough Limestone.

Sh. 0' 3"
 Sa. 25' 9"
 Sh. with 4" Coal ... 12' 6"

RICHMOND HILL.

Sh.	...	...	17' 0"
Sa.	...	...	11' 0"
Sa.	...	...	5' 0"
Sh.	...	...	12' 0"
Limestone	...	...	2' 6"
Sh.	...	...	3' 0"
Sa.	...	...	3' 6"
Sh.	...	...	10' 0"
Sa.	...	...	2' 0"
Sh.	...	...	10' 0"
Sa.	...	...	1' 0"
Sh.	...	...	55' 0"
Sa.	...	...	16' 6"
Fireclay	...	...	2' 3"

The 30-inch limestone in the Richmond Hill boring has been seen outcropping between Ouston and Richmond Hill, and near Nesbit Hillhead. Further to the south-west a thin limestone of similar horizon appears in the bed of a small stream near Welton. The Geological Survey record it in Shildonhill Plantation and in the road west of Shildon Hill. A thin limestone at this horizon outcrops in the bed of the South Tyne near Wydon^t. A coal below the Thornbrough limestone has been seen on the surface at Crook Hill, near Thornbrough.

The sandstone immediately below the Thornbrough limestone has been quarried for building material at Nesbit Hillhead and at Pike Hill, near Ouston. It forms the eminence of Slate Hill, between Black Heddon and Belsay, and at Shildon Hill can be seen as a coarse white grit 20' thick. Further south-west it forms Gallow Hill near Corbridge.

Thornbrough Limestone. The Thornbrough limestone has been quarried for lime-burning at Thornbrough Kiln House, at Aydon South Quarry, and to the North of High Barns. A lead vein which appears in the limestone here was worked at an early period. An attempt to re-establish a lead mine in 1801 led to the discovery of numerous old workings. A further unsuccessful attempt to work the lead was made in 1872 by The Thornbrough Mining

Company Beside Newton Fell House the line of strike is interrupted by the Newton-Shildon fault, which has a downthrow to the west. From this point to Whittlestone the line of outcrop is obscured by surface deposits of considerable thickness. At Welton a borehole sunk for water failed to reach rock at a depth of 120ft. North of the Whittlestone reservoirs the outcrop can be seen in old workings at Nesbit. The limestone outcrop crosses the river Pont at Heugh Mill, and has been quarried at High House, to the south of Brixton Hill, and at Chapel House. At Robsheugh and Huntlaw it is still worked to some considerable extent. From here the line of strike is almost due north, past West Bitchfield and through Belsay South Park. A boring at Stob Hill records 184 $\frac{1}{2}$ " of Thornbrough limestone.

The Thornbrough limestone and its accompanying shale beds contain Dibunophyllid and Zaphrentid corals in great numbers. *Pustula punctata* (Mart) is also usually present.

A basalt dyke has been recorded in the limestone at Thornbrough.

The beds between the Thornbrough and Harlow Hill limestones were sunk through in a borehole put down at Stob Hill in 1880 —

Harlow Hill Limestone			
Blue Post	.. .	0' 9"	Blue metal with girdle 5' 9"
White Post	.. ..	0' 3"	Grey Post . . . 2' 0"
Grey Metal	.. ..	1' 8"	Blue metal and girdle 2' 5"
Grey Post	.. ..	1' 8"	Blue Metal .. . 0' 8"
White Post	.. ..	4' 1"	White Post . . . 2' 5"
Black Metal	.. ..	0' 8"	Blue metal bed . . . 0' 5"
Grey Post	.. ..	2' 3"	Grey Post . . . 0' 6"
Grey Metal	.. ..	1' 3"	Dark blue metal . . . 4' 6"
Grey Post	.. ..	4' 11"	Dark metal with girdle 8' 6"
Black Metal	.. ..	8' 0"	White Post . . . 0' 9"
Very hard girdle	.. .	0' 9"	Blue Metal . . . 24' 2"
Grey Metal	.. ..	1' 8"	
Whin girdle	.. ..	0' 7"	
Grey Post	.. ..	2' 8"	
			Thornbrough Limestone.

Harlow Hill Limestone. The outcrop of the Harlow Hill limestone apparently crosses the Tyne just above Styford

Hall It seems to have been quarried at one time in the field north of Styford High Barns Crossing the Brock hole Burn near the Fivepound Well, the line of strike can be clearly seen in a series of old quarries extending past Crossedge farmhouse to the road leading from Shildon to Newton On the east side of this road the limestone is still quarried for road metal After meeting the Shildon-Newton fault the line of strike is further to the south, past Whittington Hill and Stelling Hall At Harlow Hill the working of the limestone has left a wide deep trench round the west side of the hill which can be seen from a considerable distance it has also been quarried in the field south west of the village At Stob Hill a quarry with a face of 23ft is still worked and traces of a small lead vein have been seen From Stob Hill to Cheeseburn Grange the limestone has been almost worked out Limestone quarries on the Cheeseburn Grange estate were amongst the properties registered by Ralph Widdrington in 1718 Under the mansion house of Cheeseburn Grange the limestone has been met with in the laying of drains The line of strike near the River Pont is affected by a fault with a considerable downthrow to the south and the limestone next appears in the bed of the river near Dalton Mill Northward the limestone appears in the Quarry Plantation at Milburn, and has been quarried at East Bitchfield Borings near Belsay Burn in 1727 (B & S 122 123 & 124) came on the limestone close to the surface

The Harlow Hill limestone can be easily identified by the presence of a thick layer of Iithostrotion corals, which in this district at least is invariably present Overlying the coral bed is a bed of *Productus giganteus* (Mart), *P latissimus* and intermediate forms

As already stated the Harlow Hill limestone is the highest calcareous bed which can be traced continuously across the district and has been taken as the upper limit of the sequence dealt with in this paper

Two specimens, identified as *Pleuronaiulus nodosocarinatus* (Roemer) by Mr J Wilfrid Jackson, have been obtained from a fossiliferous calcareous shale near Styford

Hall on the north bank of Lyne, some two miles west from Bywell Bridge. This shale was originally mapped by the Geological Survey as being above the Harlow Hill Limestone. Later Lebour and others suggested that the bed was equivalent to the Harlow Hill limestone, and this suggestion was adopted by the Survey after the revision of the district had been made between 1899 and 1892. Dr Stanley Smith considered the shale to be of the horizon of the Thornbrough limestone. The entire absence of gigantid products and corals and the field evidence preclude both these theories. On the south side of the Tyne a calcareous shale in the March Burn near Dilton Foot has a similar assemblage of fossils to the shale at Styford and may be of the same horizon. The Styford Shale is probably 80 to 100 feet above the Harlow Hill Limestone. Two fragments referable to *Pleuronautilus nodosocarinatus* have been found in the Harlow Hill Limestone at Crossedge and Stob Hill. Associated with *Pleuronautilus* at the latter locality is a *Solenochelus*, probably *S. latiseptatum* (de Kon).

The species *P. nodoso carinatus* was originally described by Roemer⁶ and was redescribed by Armstrong⁷ as coming from 'the Upper Carboniferous Limestone Series of Clydesdale, to which group it would appear to be restricted'. The localities given are Castlecary, Arden and Garnkirk—Upper E or Lower H Zone. Foord and Crick⁸ state that Armstrong's species is undoubtedly the same as Roemer's, and Foord⁹ in describing a specimen from the Millstone Grit of Caton, Lancs., gives some of the associated fauna as *Pleuronautilus armatus* (Sow.), *Solenochelus latiseptatum* (de Kon), and *Actinoceras sulcatulum* (McCoy), the latter two of which are recorded from Arden Quarry, Clydesdale.

P. nodoso carinatus has been obtained from the Edale Shales (Upper E Zone) of Derbyshire, above the Maen Limestone of Wensleydale (probably base of E zone), from the Sneyd Gill beds of Cumberland, and in the Cayton Gill Beds in Yorkshire (Lower R Zone).

Down Hills Limestone. The problem of the horizon of

the limestone exposed at Down Hills near Halton remains to be solved. The limestone at this place is at least 15ft thick and is very much brecciated, and otherwise shews considerable signs of disturbance. The earlier geological survey identified the limestone as the "Little", but later editions refer to it as "a boulder of limestone". Stanley Smith considering its relation to the limestone and coal proved in the coal workings and borehole in the field to the north pronounced the exposure to be "Corbridge" Limestone¹⁰. At this time however the existence of three Oakwood limestone had not been shewn, and Smith's identification of the limestone in the Clare Wood boring with that normally occurring about 65ft below the Corbridge limestone, can now be shewn to be incorrect. The fact that the coal worked at one time at Halton Shields lies below the thin limestone of the boring seems to preclude Down Hills from being Little Limestone, but at the present time the writers of this paper are not prepared to offer any nearer solution.

Palaeontology — During the time that the writers have been investigating the problems detailed in this paper and for some years previously they have acquired over one thousand specimens of fossils and it is hoped to publish lists of these at some later date.

APPENDIX

Schedule of Boring, Sinkings and Sections
Record of Boring and Sinkings—North of England Institute of
Mining and Mechanical Engineers

- 103 Belsay Barns Colliery
- 104 Bored in Calley Burn in the S E corner of the meadow field, near a place where a trial was made for coal in Bitchfield Estate—2nd October, 1757
- 106 To the southward from Belsay Barns about 200 yards and West from the Road—11th May 1758 Lat 55° 5' 38" Long 1° 54' 45"
- 107 In the south east part of Leagues Field to the east from Belsay Mill—June, 1758
- 108 In the Leagues Field, near Davie's Mill, near an old mill-stead, and north from rivulet in Hewitt's ground—Dec., 1752
- 114 In the old pit at Belsay Barns—9th Sept., 1771
- 115 Belsay At the Craggs near the Burnside
- 119 Near Belsay Barns and ½-mile N F from Boghall Colliery Lat 55° 5' 38" Long 1° 57' 31"

- 120 About 300 yards East from the Engine at Belsay Barns Lat 55° 5' 58" Long 1° 55' 14"
 125 Near Belsay Barns, about halfway between an old pit and the Barns and West side of road Lat 55° 5' 40" Long 1° 55' 38"
 250 Section of working pit at Boghall 1868 Lat 55° 0' 58" Long 1° 55' 28"
 261 Section of old Engine Pit at Boghall Lat 55° 5' 30" Long 1° 55' 48"
 286 Boring at Brandyhall near Blytheside 179" Lat 55° 6' 15" Long 1° 55' 9"
 287 Brandyhall 240 yards West from No 286 Lat 55° 6' 14" Long 1° 55' 20"
 288 Brandyhall 100 yards South from No 286
 1243 Kirkheaton About 50 yards West from Boghall Lat 55° 5' 49" Long 1° 56' 15"
 1247 Kirkheaton At Blytheside about 100 yards East from the ford Lat 55° 6' 8" Long 1° 56' 42"
 1249 Section at Kirkheaton Colliery
 544 Corbridge Section of pit at Deanside 1867 Lat 4° 59' 18" Long 2° 0' 28"
 836 Fallowfield Section of strata from the Little Limestone
 887 Fallowfield Section of Halfway Pit Lat 55° 0' 9" Long 2° 6' 45"
 838 Fallowfield Lat 55° 0' 35" Long 2° 6' 21"
 999 Aydon Eastside About 450 yards N W from White House —1757 Lat 55° 0' 9" Long 1° 58' 45"

Report on the Carboniferous Limestone Formation and its Coal Resources N of T Inst Min & Mech Eng 1912 —

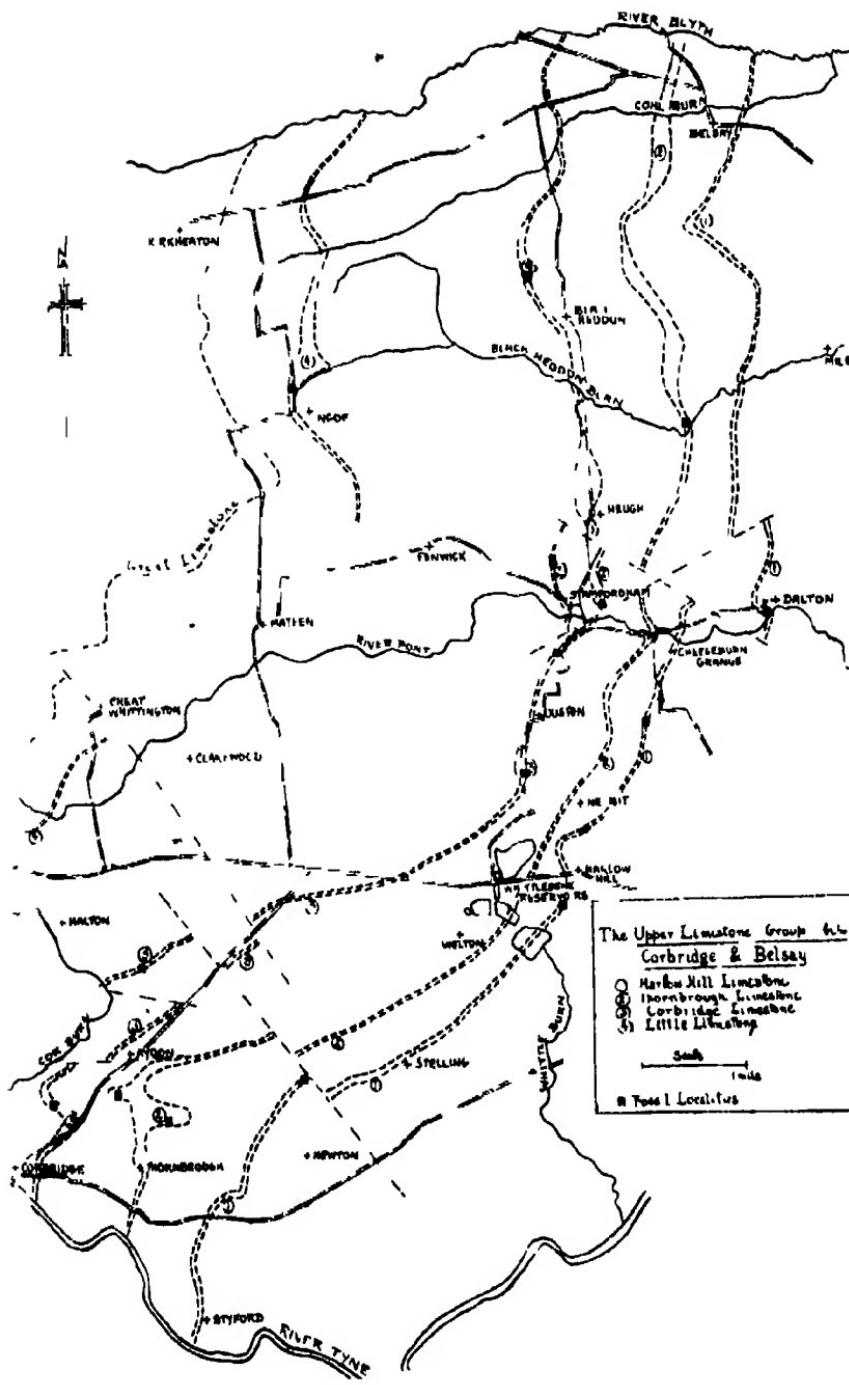
Grace Pit	Kirkheaton	Fenwick Pit No 1
Matfen Tilery Boring		Fenwick Pit No 2
Borehole near Halton		Corbridge Pottery

By permission of Mr Bates of the Mickley Coal Company
 Boring at Dilston Bridge Boring at Craneshaugh

Cheeseburn Grange Estate Papers
 Boring in Stob Hill Quarry—June 1880
 Boring at Richmond Hill by Thos Lawe—May 1907

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- ¹Trotter and Hollingsworth, *Summary of Progress of the Geological Survey of Great Britain* 1927, App II, pp 98 A Seg
²Lebour, G A, "The Geology of the Corbridge District," *Trans Berwick Field & Nat Club* 1884, Vol X, p 196
³Lebour, G A, *loc cit* See also *Summary of Progress* 1926, p 108
⁴*Summary of Progress*, 1926, p 102
⁵Lebour, G A, *New County History of Northumberland* Vol VI, p 11
⁶Roemer, *Zest d Deut Geol Ges* 1863, Bd XV, p 577, taf XIV, ff 8 a c
⁷Armstrong, *Trans Geol Soc Glasgow*, 1805, Vol II, p 74, pl I, ff 6, 7
⁸Foord & Crick *Cal Foss cpl Brit Mus*, 1801, Pt II, p 130
⁹Foord *Geol Mag* Dec III, Vol VIII, 1801, p 481
¹⁰Smith, Stanley *Trans N of Eng Inst Min Mech Eng*, 1912, p 52



NOTE ON HIGH TEMPERATURE PRODUCTS OF
IRON WITH HYDROGEN SULPHIDE, CARBON
DISULPHIDE AND HYDROGEN SULFIDE

By J B PEEL M Sc Ph D A I C and
P L ROBINSON D Sc F I C

Hydrogen Sulphide Pure iron was heated to 1000° in pure dry hydrogen sulphide the reaction began about 350°, but was slow below 900°) and the product cooled in nitrogen giving a silver white crystalline material permanent in air, and with sufficient sulphiding non magnetic. It reacted extremely slowly with hydrochloric acid displaced neither metal from solutions of copper sulphate or bismuth nitrate, and analyses indicate that its composition was exactly FeS. The density was 4.630 as compared with 4.67 usually given for ferrous sulphide. There was obviously a metamorphic change in cooling as the mass fell to a powder at the touch but no thermal arrest was found below 150°, whereas in agreement with others material containing traces of free iron was found to have an arrest at 138° and commercial ferrous sulphide one at 128°. Ferrous sulphide is usually regarded as stable when heated in hydrogen but with this material reduction began much below and was appreciable at 800° (For previous literature see 'A Text book of Inorganic Chemistry' Vol IX Pt 2, by J Newton Friend)

Carbon disulphide — The experiment by which Gautier and Hallopeau¹ claimed to have prepared a subsulphide of iron Fe₄S₃ by the action of carbon disulphide on metallic iron at 1900° was repeated at 1000°. At this temperature the product partially fused and on cooling left a brittle, greyish-white crystalline mass containing some free carbon from the greater part of which the sulphide could be separated mechanically. It differed from the material described above in being almost completely magnetic and slightly variable in composition the mean of a number of analyses giving Fe 67.0, S 32.8%, corresponding most closely to

Fe_2S_3 . It is believed that these differences were not due to the presence of a sub sulphide but rather to incompleteness of the reaction magnetic material of similar order of composition having been obtained in the experiments with hydrogen sulphide when the time allowed for conversion was insufficient.

The vapour issuing from the furnace proved on condensation to be unchanged carbon disulphide.

(With C I Marvin)

Hydrogen selenide—Selenides have been prepared previously by heating selenium and iron filings¹ but not by heating iron in hydrogen selenide. This latter reaction at 750 gave a fused product which on cooling was a silver white crystalline magnetic substance with a density of 6.211 acquiring a grey appearance in air and liberating hydrogen selenide with concentrated hydrochloric only when metallic iron or a similar metal was present. Analyses show that the product varied in composition and was about 3% richer in selenium than ferrous selenide. This retention of selenium by the ferrous selenide was different from the behaviour of the sulphide and was possibly due to the lesser volatility of selenium.

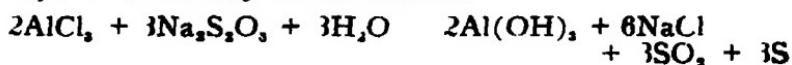
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A CRITICAL EXAMINATION OF CHANCEL'S
METHOD FOR THE SEPARATION OF IRON AND
ALUMINIUM

By P. I. LUCOCK ROBINSON, D.Sc. F.I.C., and
W. E. SCOTT M.Sc.

The gravimetric separation of iron and aluminium is difficult by reason of the similarity in the properties of the two trivalent ions and the fact that the precipitates given by these are invariably of the type which readily absorb soluble material at the moment of formation and tend to retain it during the washing process. The method under consideration was first suggested by Chancel¹ although an identical procedure is ascribed to Bunsen² by Parnell³ and depends essentially on the reaction



Since ferrous hydroxide is a relatively strong base ferrous salts are not hydrolysed under the conditions employed and thus neither this compound nor basic salts are precipitated. No figures indicating the accuracy of the method are given in the original paper but the later communication states that the whole of the alumina is thrown down after 10—15 minutes' boiling. Contrary to this, Stead⁴, found that the method gave low results for aluminium even after boiling for 30 minutes and recommends the addition of sodium phosphate, giving in support the results obtained on 10 gm of pure iron with 0.064% of aluminium (Table I)

TABLE I

With phosphate	30	0.128	+ 6.2
Without phosphate	30	0.053	- 56.9
Without phosphate	120	0.123	+ 1.6

Carnot⁵ appears to have arrived independently at the view of Stead, and certain subsequent workers have added other precipitants along with the thiosulphate, but since the

present investigation deals with the use of thiosulphate alone, it is only necessary to mention this here. The sole evidence on the conditions necessary for the complete precipitation of the aluminium, that of Parnell (*loc. cit.*) and Stead (*loc. cit.*) is contradictory, and it was with a view to establishing the accuracy of this convenient separation, doubts upon which have recently been expressed^b, and the optimum conditions, that this work was undertaken. It has resulted in showing that there is an uncertainty in the alumina found of the order of 2° of the amount present, and that to obtain even this accuracy, periods of boiling, considerably longer than is normally convenient, are necessary.

METHOD AND MANIPULATION

Standard solutions of iron and aluminium were carefully made using ferrous ammonium sulphate and pure aluminium foil respectively. These were pipetted into beakers of 1 litre capacity where a dilute solution of sodium carbonate was added in quantity just insufficient to produce a precipitate. The solution was diluted to about 600 ccs with water and a weighed quantity of sodium thiosulphate, dissolved in water, was added. These quantities were varied in the several experiments.

The solution was then raised to boiling and maintained thus for periods varying from 25—10 hours. At the commencement of heating the evolution of sulphur dioxide could be detected with dichromate paper but in less than 30 minutes this test failed to give a positive result, although a sulphurous smell, characteristic of hot water carrying suspended sulphur was observable during the whole course of this operation. The precipitate thrown down consists of a mixture of aluminium hydroxide and sulphur and is quite unlike the voluminous, gelatinous hydroxide normally obtained, being similar in character to the magnesium ammonium phosphate precipitate and tending, like it, to adhere to any part of the surface of the beaker which has been scratched in the course of precipitation. It was repeatedly washed with water by decantation and on the

paper and was transferred to a tared crucible wherein it was first dried, then gently heated until the sulphur was volatilised, and finally ignited to constant weight in a muffle furnace. The ignited alumina showed the hygroscopic properties observed by other experimenters. It contained small quantities of sodium sulphate, which varied in amount with the thiosulphate used, but only negligible traces of iron.

The iron remaining in the filtrate after the separation of the aluminium was estimated by decomposing the excess of thiosulphate with hydrochloric acid, boiling until the liberated sulphur was coagulated completely, oxidising the iron and precipitating it as ferric hydroxide. This was filtered off along with the sulphur burnt off and weighed as ferric oxide.

An examination of the results, which are summarised in Table II, in regard to concordance makes it evident that differences within the individual groups are due, at least in part, to variations in the rates of evaporation of the liquids by boiling; actually it was possible to forecast, from the appearance of the boiling liquids, which estimation in a group would give the highest result. The most concordant results are those in Group K in which the rates of boiling were maintained as far as possible the same. The erratic results of Group D are probably due to a deficiency of thiosulphate, the minimum quantity necessary appearing to lie between 5.4 and 7.7 grams per 0.2 grams of aluminium. With identical quantities of thiosulphate an extension in the boiling period by $\frac{1}{2}$ -hour resulted in an increase of 4.7%, by 3 hours of 7.0%, and by $7\frac{1}{2}$ hours of 15.5% in the separation of the alumina, and this main conclusion, that the amount separated increases with longer boiling, being incomplete under 10 hours, is borne out by the results of all groups. The exclusion of iron in groups H and I indicates that this material has no effect on the degree of separation of aluminium obtained.

The separation allows of a satisfactory recovery of the iron by precipitation as hydroxide.

TABLE II

F-tn	Na ₂ SO ₄ grams	Boiling (hrs.)	Al ₂ O ₃ found (grams)	Mean diff from mean (% of mean)	Gain or Loss %
A { a b	10	2½	0.2175 0.2199 0.2192 (mean) 0.2189	0.42	+ 1
B { a b c	15	3	0.2741 0.2673 0.2685 (mean) 0.2699	1.00	- 8.8
C { a b c	10	3½	0.2295 0.2316 (mean) 0.2306	0.48	- 9.4
D { a b c d		4	0.1650 0.2510 0.2182 0.2562		-
E { a b c	18	4	0.3303 0.3289 0.3325 (mean) 0.3290	0.61	+ 1
F { a b	11	5	0.2883 0.2961 (mean) 0.2912	1.68	- 1.7
G { a b	13	6	0.2888 0.2924 (mean) 0.2906	0.02	- 1.9
H { a b	30	6	0.2926 0.2943 (mean) 0.2936	0.24	- 1.0
I { a b c	7	7	0.3463 0.3383 0.3407 (mean) 0.3417	0.88	- 0.8
J	14	7	0.3423	-	- 0.6
K { a b c	10	10	0.3111 0.3098 0.3094 (mean) 0.3101	0.23	+ 1.4

Notes on certain individual estimations:

- P { a
b Boiled at half the rate of b
Boiled extremely vigorously and took almost to dryness before making up with water. Probably it means mean boiling period of group to 5½ hours.
- H { a
b Boiled at the same rate as C
- I { a
b
c Boiled very rapidly
Boiled very gently
Boiled at average rate
- R { a
b
c In this group the rates of boiling were made as near equal as possible
The period of boiling was timed to a minute and exact allowances made for periods off the boil after water had been added

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THE NATURE OF INTELLIGENCE.

BY GODFREY H. THOMSON, D.S.C., PH.D.

The greater part of this address dealt with a controversial matter which I would rather not write at length upon without more leisure in which to choose words with care. It can, however, be outlined in a few sentences. Professor Spearman noted many years ago that the correlations between mental tests show a relationship which is nowadays described by saying that the tetrad difference tends to be zero. That is to say, in the correlations r of four tests $x_1 \ x_2 \ x_3 \ x_4$

	x_1	x_2
x_3	r_{13}	r_{23}
x_4	r_{14}	r_{24}

the tetrad difference

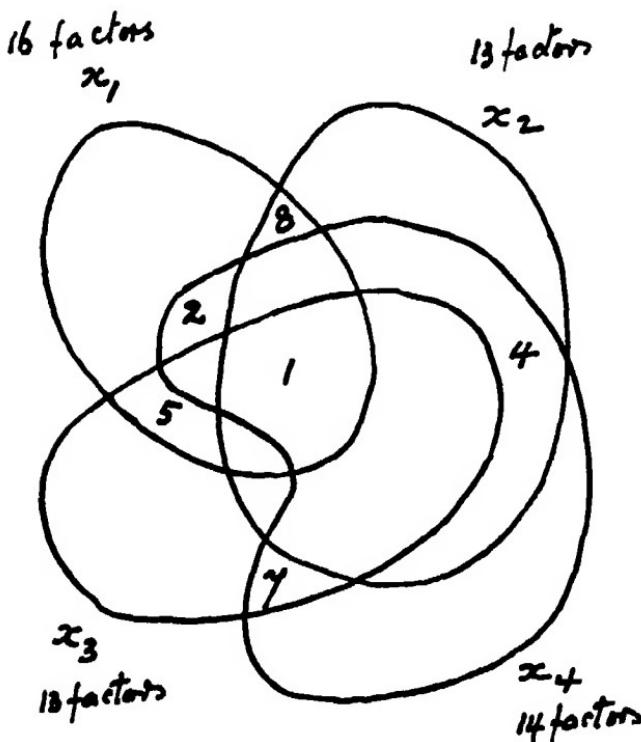
$$r_{13} r_{24} - r_{14} r_{23} = 0$$

or in actual experiment tends to be grouped round zero. Professor Spearman explains this by the hypothesis that each activity is performed by a "general intelligence" g , common to all activities, and a "specific factor" s , unique to that activity alone. It is easy to show that this is a possible explanation, and Professor Spearman and his disciples have made it the inspiration of a great deal of extremely valuable work. Disliking, however, the creation of entities like " g " I have preferred to assume only that each mental activity is a sample of a large number of factors (whether inherited or acquired)—that the reason we are successful in a test flows from a large number of items in our heredity and in our experience. On this theory, too, the tetrad differences will be grouped about zero.

Such is a bald and incomplete outline of two theories which possibly are only different ways of looking at the

matter. My own attitude may perhaps be summed up by saying that I do not object to Professor Spearman's theory as a convenient description, but think it dangerous as a causal explanation. In my opinion the phenomenon is the same sort of thing as the simpler phenomenon of the "normal," Gaussian or Laplace distribution of many measures of a physical quantity.

I would rather turn to a non-controversial matter on which I touched in the last quarter of my address. It is not original, but the particular treatment here given is



"elegant" and not, I think, easily accessible anywhere in one place; and I add an illustrative example using my own device of a "structure diagram."

The problem is to find a team of tests which will correlate highly with some given criterion. Let x_1 be the

criterion and x_1, x_2, x_3, \dots the scores in the tests. The first member of this team one chooses, naturally, because the correlation r_{12} is high. Each later member of the team is chosen because its correlation with the criterion is high, and its correlation with the pre-existing team low (when it is added) or *vice versa*, because its correlation with the criterion is low and with the team high (when it is subtracted). The best weights have then to be found for the scores of the tests—to give the best correlation with x_1 . These weights, formerly obtained by a cumbersome calculation of partial correlations, we nowadays calculate from the determinant

$$\Delta = \begin{vmatrix} 1 & r_{12} & r_{13} & r_{14} \\ r_{12} & 1 & r_{23} & r_{24} \\ r_{13} & r_{23} & 1 & r_{34} \\ r_{14} & r_{24} & r_{34} & 1 \\ \cdot & \cdot & \cdot & \cdot \end{vmatrix}.$$

They are, relatively to one another,

$$\frac{\Delta_{12}}{\sigma_1} x_1 - \frac{\Delta_{13}}{\sigma_2} x_2 + \frac{\Delta_{14}}{\sigma_3} x_3$$

where the σ 's are the standard deviations of the corresponding x 's. The correlation of the weighted team with the criterion is then

$$R = \sqrt{1 - \frac{\Delta}{\Delta_{11}}}$$

To illustrate this process consider the following structure-diagram :

Each of the four variables is represented by a closed curve. The curves overlap so as to show 1 space common to all, 4 spaces each common to three, 6 spaces common to two variables, 4 specific spaces, and 1 outer darkness (the binomial co-efficients 1, 4, 6, 4, 1). Some of the spaces

are blank, but some contain factors which assist the "mental tests" in question (x_1 , x_2 , x_3 , or x_4). Thus there is one factor which helps all four, and seven which help both x_1 and x_4 , etc.

The correlations of four such variables can be calculated by the formula

$$r = \frac{\text{Common factors}}{\text{Geom. mean of the two totals.}}$$

and to one decimal place only (to save arithmetic) they are

	x_1	x_2	x_3	x_4
x_1	—	.6	.4	.2
x_2	.6	—	.1	.4
x_3	.4	.1	—	.6
x_4	.2	.4	.6	—

Now treat x_1 as the criterion and x_2 , x_3 , x_4 as the scores in three mental tests, forming a team to correlate with (or measure as well as possible) that criterion. What are the best weights? By the above explained process they are found to be (supposing the standard deviations to have been equalized as is usual)

$$.37 x_2 + .31 x_3 - .23 x_4.$$

Very approximately this is

$$x_2 + x_3 - x_4$$

and by examining the structure diagram we can see that this is plausible. For x_1 measures $8+1$ factors within the criterion, but also unfortunately 4 unwanted factors outside. x_2 measures $5+1$ factors within the criterion, but also 7 unwanted factors outside. The 1 central factor has now alas been measured twice. Luckily, however, subtracting x_4 removes one of these, and removes also those 4 and those 7 extraneous factors which are not in the criterion. The team $x_2 + x_3 - x_4$ therefore measures

nothing *outwith* the criterion (as we say in Scotland) and measures once most of the factors forming the criterion, though unfortunately 2 are taken negatively, which prevents the correlation from being perfect. With the best weights that team correlation is

$$R = \sqrt{1 - \frac{\Delta}{\Delta_{11}}} = .76$$

By means such as these teams of tests can be built up to correlate with any independent criterion of intelligence (such as the teacher's) or, for vocational guidance, with criteria of success in a trade.

THE IDENTITY AND GEOLOGICAL HORIZON
OF THE COAL SEAM EXPOSED IN THE
EARLY AUTUMN OF 1930 ON THE FORE-
SHORE AT SEATON SLUICE, NORTHUMBER-
LAND.¹

BY WILLIAM HOPKINS, M.Sc., PH.D., F.G.S.

A considerable amount of local interest was aroused in the early autumn of 1930 by the discovery of an outcrop of coal on the foreshore to the north of Seaton Sluice. The seam apparently was laid bare by the scouring action of the tides removing the covering of sands. At favourable times, the seam can be seen on the foreshore opposite the junction of the roads from Blyth, Seaton Sluice, and Seaton Delaval Hall. The aim of this communication is to place on record the identity and geological horizon of the seam.

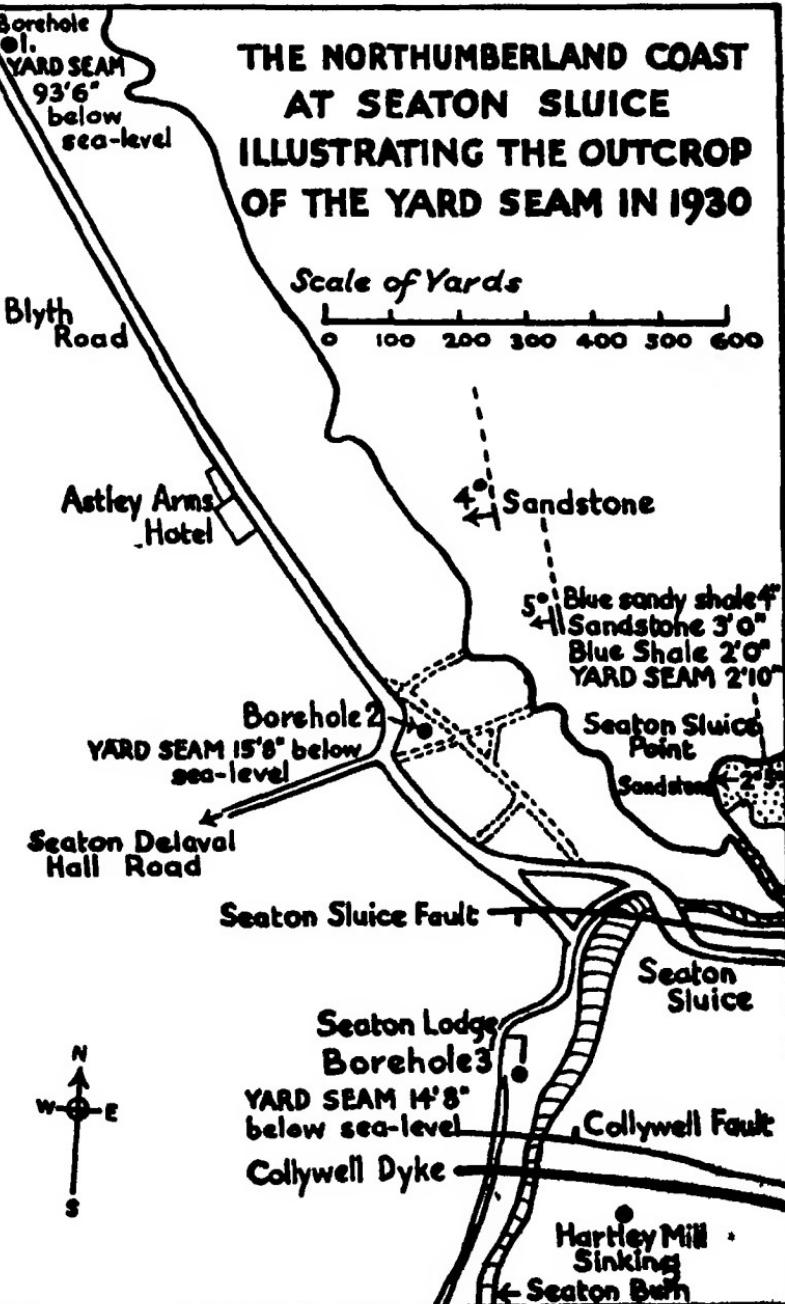
In 1926, Dr. Absalom and I communicated a paper to this society dealing with the Geological Relations of the coast sections between Tynemouth and Seaton Sluice (*loc. cit.*). In this paper, the correlation of the seams outcropping in these coast sections is given with reference to their respective equivalents occurring in the collieries of the coalfield. We stated that the Yard seam outcrops under the dunes to the north of Seaton Sluice (p. 144).

There can be no doubt from the evidence put forward in the 1926 paper, that the newly discovered outcrop of coal is the Yard seam. This conclusion is deduced from the following sources of evidence :

- (a) The geological horizons of the strata in Collywell Bay, particularly that of the Seaton Sluice Point Sandstone at the extreme north end.

¹ An appendix to the paper on "Geological Relations of the Coast Sections between Tynemouth and Seaton Sluice." Absalom and Hopkins. *Proc. Univ. Durh. Phil. Soc.*, VII, p. 142. 1926.

**THE NORTHUMBERLAND COAST
AT SEATON SLUICE
ILLUSTRATING THE OUTCROP
OF THE YARD SEAM IN 1930**



- (b) The lithological characters of the recently exposed outcrops together with their general strike and dip.
- (c) The records of boreholes put down near Seaton Sluice as follows :
 - (1) On the links between Gloucester Lodge Farm and the Astley Arms Inn in 1890 on the Seaton Sluice-Blyth coast road;
 - (2) on the links at the junction of the roads from Blyth, Seaton Sluice and Seaton Delaval Hall in 1891; and
 - (3) at Seaton Lodge, Seaton Sluice, in 1891.
- (d) The records of colliery sinkings at Hartley and Newsham.

Details of the boreholes mentioned above appear in the *Supplementary Volume of Borings and Sinkings of Northumberland and Durham*, published by the North of England Institute of Mining and Mechanical Engineers. The reference numbers are 2739, 2740 and 2741. The positions of the recently exposed outcrops, the sites of the boreholes and other relevant matter are shown in the accompanying map.

Collywell Bay.

The north and south ends of Collywell Bay are composed respectively of the Seaton Sluice and Crag Point Sandstones. Dr. Absalom and I have given reasons for regarding these sandstones as equivalent. They form the greater part of the strata between the Yard and Bensham seams in these coastal districts. The Bensham seam can be seen underlying the Crag Point Sandstone to the south of the Crag Point Fault. The Yard seam is exposed in Collywell Bay overlying shales which succeed the Crag Point Sandstone. It has, however, been cindered by the Collywell Dyke.

At the north end of the bay, the prominent Seaton Sluice Point Sandstone is exposed. It is at least 50 feet thick and at the extreme north end, i.e. at a distance of 250 to 300 yards from the recently exposed coal seam; the

beds strike 5° West of North (magnetic) and dip gently at an angle of $2-5^{\circ}$ in a direction 5° South of West (magnetic). Since the magnetic declination is approximately 13° West, then the corrected true readings for these beds are as follow : strike 18° West of North and dip in a direction 18° South of West. To the south, the sandstone is faulted by the Seaton Sluice Fault against strata associated with the High Main seam. The 70 Fathom Sandstone Series overlies the High Main strata and extends to the Collywell Fault some 20 yards north of the Collywell Dyke. In our 1926 paper we give a map and sections illustrating these points.

The Recently Exposed Outcrops.

I have seen two outcrops exposed. The larger one occurs on the foreshore at a distance of 220 yards from the junction of the roads from Blyth, Seaton Sluice and Seaton Delaval Hall. It can be approached by walking along the cart track from the junction of the roads through the cutting in the dunes. It is also some 250-300 yards from the point where the Seaton Sluice Point Sandstone dips under the foreshore.

The outcrop is some 30 yards long. The succession of strata exposed is as follows :

Blue sandy shales	4 inches.
Sandstone	3 feet.
Blue shales	2 feet.
Coal	2 feet 10 inches.

The coal can only be seen when the scouring action of the tides is strongly marked. The most southerly point of the outcrop is some 50 yards from the sandhills. The beds are striking 10° West of North (magnetic) in the direction of Blyth lighthouse, i.e. 23° West of North (true), and have a gentle dip of 5° in a direction 10° South of West (magnetic), i.e. 23° South of West (true). These directions then, correspond approximately with the strike and dip directions of the most northerly exposure of the Seaton Sluice Point Sandstone some 250-300 yards further south.

There can be no doubt that the recently exposed beds under consideration conformably succeed the Seaton Sluice Point Sandstone series. The higher part of the Seaton Sluice Point Sandstone series, which probably includes some more beds of sandstone and a little shale, is not visible owing to the covering of sands. The thickness of this hidden part of the succession cannot be more than from 15 to 20 feet. The seam recently exposed on the foreshore must therefore be the Yard if the correlation of the Seaton Sluice Point Sandstone is correct, as it is believed to be.

The second exposure occurs some 110 yards higher up the coast from the first one, and some 30 yards from the sandhills. The beds exposed are made of sandstone and show pronounced rectangular jointing. They are striking roughly North and South (magnetic) and have a dip of 4° in a Westerly (magnetic) direction. It would appear that this sandstone is simply an upward continuation of the succession at the first exposure. The intervening ground is covered with sand.

Evidence of Boreholes and Colliery Sinkings in the Neighbourhood.

Further, the sandstones and shales overlying the recently exposed seam can be correlated with those recorded above the Yard seam in the boreholes mentioned previously. There can be no doubt that the seam recorded in the three boreholes is the Yard. This can be shown by comparing the vertical sections with those of colliery sinkings in the neighbourhood, as for example at Hartley and Newsham. Dr. Absalom and I have illustrated the correlation of these seams in the figure of plotted vertical sections in our 1926 paper.

The following records are of the depths of the Yard seam below sea-level in each of the three boreholes, together with the lithological character of the relevant strata above the Yard seam.

Borehole 1. On the links between Gloucester Lodge Farm and the Astley Arms.

Depth of Yard seam below sea-level	93 feet 6 inches.
Sandstone	28 feet 8 inches.
Shale	3 feet.
Yard seam	2 feet 6 inches.

This borehole is the farthest from the recently exposed seam.

Borehole 3. At Seaton Lodge, Seaton Sluice.

Depth of Yard seam below sea-level	14 feet 8 inches.
Sandstone	13 feet 6 inches.
Shale	5 feet.
Yard seam	2 feet 8 inches.

This borehole is some 640 yards from the recently exposed seam. It is on the south side of the Seaton Sluice fault. On the coast, the 1926 paper gives this fault as having a down-throw to the south of 180 feet. The fault, however, dies out very rapidly inland and probably has only a small throw, if any, to the north of the borehole.

Borehole 2. On the links at the junction of the roads from Blyth, Seaton Sluice and Seaton Delaval Hall.

Depth of Yard seam below sea-level	15 feet 8 inches.
Sandstone	18 feet 6 inches.
Shale	3 feet.
Yard seam	2 feet 8 inches.

This borehole can only be about 200 yards from the recently exposed coal seam.

Further, at Hartley Mill sinking on the south side of the Collywell Fault, the Yard seam is overlain by shale and sandstone as follows :

Sandstone	22 feet 2 inches.
Shale	3 feet 6 inches.
Yard seam	3 feet 4 inches.

Again, at Newsham Hannah Colliery about one mile south-west of Blyth a modified succession prevails as follows

Sandstone	7 feet
Yard seam	2 feet 11 inches

The shale overlying the sandstone has apparently passed laterally into sandstone. Indeed it would appear that in the coastal districts under consideration the Yard seam is overlain by thin shales succeeded in turn by a prominent sandstone. It follows therefore that the recently exposed coal seam is the Yard, i.e. the seam succeeding the Seaton Sluice Point and Crag Point Sandstone seam.

Conclusion

From the evidence given there can be no doubt that the recently exposed coal seam is the Yard seam of Northumberland, i.e. the Main Coal of Durham. The same seam can be seen in Collywell Bay where it has been cindered by the Collywell Dyke. It can also be seen near the top of the cliffs at Sharpness Point at the south end of the Long Sands, Tynemouth. It also outcrops in the cliffs to the north of the Permian exposures at Cultercoats but unfortunately is not visible owing to the cliffs being walled up at that point.

THE GENERATION OF ELECTRIC CURRENTS BY WATER MOVING IN A MAGNETIC FIELD

By H. C. REGNART, M.Sc., F.Z.S.

Within a few days of Faraday's discovery of the principle of magneto electric induction he perceived that there should be an electric movement in water in motion across the earth's magnetic field similar to that which he had found in wires. The two attempts he made to observe this both failed, though over the latter of them made in the Thames at Waterloo Bridge, he spent three days with every variant in the search that his fertile brain could suggest. Bence Jones mentions in his *Life of Faraday* that some supporting evidence had been obtained later for Faraday's view when submarine cables were laid, but the direct quantitative confirmation of the presence of electric currents caused by water moving in a magnetic field does not seem to have been attempted since Faraday's time.

Magneto electric induction is probably the best known action in nature, and it might well be thought that the direct observation of the phenomenon in moving water was superfluous, but for the purpose of emphasizing the suggestion that such electric currents might play some part in deep sea, and possibly in shore life, the following experiments were made, the first result of which was to show why Faraday failed.

The electro motive force in a perfect conductor of electricity moving with velocity V in a magnetic field of intensity B lines per sq. cm. is $e = Bv/10^8$ volts per centimetre length at right angles to the direction of the field. When the moving medium in a perfect insulator of dielectric constant k , the voltage is modified by the polarization of the medium, and is $e (1 - \frac{1}{k})$. Sea water is a conducting dielectric, and the exact voltage lies between these, but since k for water is about 80 for steady fields and at low frequencies the term $\frac{1}{k}$ is negligibly small, and has not been included in the following considerations.

The first observations were made across the mouth of Cullercoats Harbour. Two large plates of rustless steel, to which insulated cables were attached, were immersed at the opposite pierheads 140 yards apart, and the wires taken to a Cambridge and Paul unipivot galvanometer on one of them. The time chosen was near low tide when the depth was not more than a few feet, and the water swung to and fro as waves surged into the harbour and receded. There were two observers, Mr. Thompson and myself; one indicated the movement of water, shown by floats, the other that of the galvanometer needle. Each wave entering the harbour drove the galvanometer needle firmly to one side, each movement of ebb to the other. Every slight change of velocity, such as that of the crest riding in over the underlying water, showed in the movement of the needle. The movements were in perfect synchronism, and the magnitude of the effect was of the right order, though since all the water between the piers does not move at the same speed the effect did not lend itself to quantitative determination.

One interesting fact was found bearing on the current views of the direction of the earth's magnetic field. The direction of the electromotive force was such that a wave entering the harbour made the plate at the north pier behave as the negative pole of the cell of which the sea formed the working liquid. The current flowed from the north to the south pier through the sea, the harbour facing east. This proves that the earth's magnetic field there pointed downwards so that the so-called North pole of the earth is really the entering or South pole of an electromagnet. This is, of course, well known, but the observation is an interesting natural confirmation of it. While the harbour is filling there is an electric current across it from north to south, during ebb in the reverse direction.

These trials were made in the winter under some difficulties of weather and exposure. The plates were therefore removed and placed in opposite sides of the stream in Jesmond Dene, and here the first of the disturbing factors subsequently encountered became evident, and

the reason for Faraday's difficulties in a steadily flowing stream became apparent. This was the difference between the polarization voltage of metal surfaces however carefully treated, cleaned, galvanized or platinized, when immersed in moving water containing air in solution. It was impossible to find close numerical agreement between the rate of movement of the water and the electromotive force. The polarization e.m.f. was too large and variable, and the flow not sufficiently uniform over the section of the stream to insure the same distribution at each plate. It was therefore decided to work indoors and to proceed by using a rapid controlled stream of water in a narrow channel rather than a wider and more sluggish stream in the weak field of the earth. In the end a glass tube $\frac{1}{2}$ centimetres bore was placed between the poles of a powerful electromagnet and fitted with exploring strips of metal at opposite sides of the tube at right angles to the field. The intensity of the field was measured by the relative change of resistance of a bismuth spiral, and the velocity of flow of the water by its discharge into a measuring tank, the supply being the water mains of the building. The latter was not altogether satisfactory; the pressure varied during the day according to other demands upon it, the temperature was liable to slow changes of several degrees, and the air content varied. The polarization of the platinum wires eventually used as exploring poles could not be controlled after the water flow was started. It could be reduced to zero or even reversed by swabbing the tube before starting to remove the surface films of air, but in the end the measurements were made by allowing the polarization voltage to float balanced on a large Crompton potentiometer, and observing, when this was for the time steady, the change of voltage produced by making or breaking the magnetic field. The influence of the length of the exploring poles was examined fully by cutting an air gap across the rim of a large ring electromagnet, which had been wound for another purpose, so that a gap 2.25 cms. wide, 5 cms. deep, and 38 cms. long was obtained in which a flux density up to 4000 lines per square centimetre could be maintained. It may be said

here that reducing the length of the tube to a few centimetres had little or no influence on the observed voltage which should theoretically depend only upon the distance of the wires apart. These were held taut by tension on opposite sides of the bore. The average clearance between them was 1.3 cms. The object in making this experiment with a long tube was to find whether the observed voltage depended at all upon the collection of charge on the wires, for in a rapid stream of water the establishment of a steady state of charge on the wires due to the induced voltage might not have been possible with short electrodes far apart as in Faraday's experiments and those at Cullercoats. This does not appear to be the case.

The observations were made by varying the speed of the water keeping the magnetic field constant or by varying the field with constant water flow. Electrodes of iron, brass, rustless steel, chrome plated steel, and platinum were tried, with little difference in the polarization due to contact with the rapidly moving water, and no influence on the voltage generated. The details of typical observations are as follows :

I. Constant magnetic field with varying water flow.

		H
Resistance of bismuth spiral . .	17.62 ohms	---
Resistance in residual field . .	17.77 ohms	500
Resistance when fully magnetized	20.04 ohms	4050

The change of field when the magnetizing current was switched on was 3550 lines per square centimetre.

(i) Velocity of Flow 53 centimetres a second.

Distance apart of electrodes 1.3 centimetres.

Polarization e.m.f.	With field applied	Difference in millivolts
58.7	61.2	2.5
65.0	67.7	2.7
77.2	80.2	3.0
78.3	80.5	2.2
88.0	90.8	2.8
		—
	Mean	2.6

$$\text{Calculated value} = \frac{BLv}{10^6} = \frac{3550 \times 1.3 \times 53}{10^6} \\ = 2.45 \text{ millivolts.}$$

Observed value/calculated value = 1.06.

Velocity of 53 centimetres a second repeated.

Polarization	With field on	Difference in millivolts
95.0	97.5	2.5
99.5	102.2	2.7
94.5	97.8	3.3
96.5	98.9	2.4
97.7	100.4	2.7
		—
	Mean	2.7

It was difficult to keep the magnetizing currents, which ranged from 47 to 50 amperes, quite constant during a run, and on making or breaking the field the changes of magnetism, depending as they do on the current, were not always exactly the same. The observations show the way in which the polarization varied, and the variation in consecutive observations of the induced voltage at each break or make, which are to some extent modified by the slight irregularities in the rate of water flow and the continual change of polarization.

(ii) Velocity of Flow 102 centimetres a second.

Polarization	With field on	Difference in millivolts
32.0	36.8	4.8
39.0	44.2	5.2
45.0	50.2	5.2
52.1	56.4	4.3
72.7	77.6	4.9
83.1	88.2	5.1
50.8	55.2	4.4
		—
	Mean	4.8

Mean observed magnetic field 3660 lines per square centimetre.

Calculated voltage = 4.8 millivolts.

Observed value/calculated value = 1.00.

(iii) Velocity of Flow 140 centimetres a second.

Polarization	With field on	Difference in millivolts.
45°	51.3	6.3
42°	48.4	6.1
46.2	52.5	6.3
50.2	56.0	5.8
60.0	66.4	6.4
62.4	68.5	6.1
		—
	Mean	6.2

Calculated value = $(3600 \times 1.3 \times 140) / 10^8 = 6.55$ millivolts.
 Observed value/calculated value = 0.942.

(iv) Velocity of Flow 187 centimetres a second.

Polarization	With field on	Difference in millivolts.
22°	31.8	9.8
83°	92.3	9.3
85.2	94.9	9.7
87°	96.5	9.5
90.3	99.7	9.4
	Mean	9.5

Field 3950 lines per sq. cm. Change of resistance of spiral
 2.22 ohms.

Calculated voltage = $(3950 \times 1.3 \times 187) / 10^8$
 = 9.6 millivolts.

Observed value/calculated value = 0.99

(v) Velocity of Flow 234 centimetres a second.

Polarization	With field on	Difference in millivolts.
20°	31.7	11.7
37°	48.3	11.3
55°	66.4	11.4
80°	91.2	11.2
90°	101.4	11.4
100°	111.4	11.4
110°	121.5	11.5
120°	131.6	11.6
	Mean	11.4

Field 3250 lines per square centimetre.

Calculated voltage = 10.8 millivolts.

Observed value/calculated value 1.055

Velocity of water cms. per sec.	E.M.F.		
	Obs.	Cal.	Ratio
53	2.6	2.45	1.06
102	4.8	4.7	1.02
140	6.16	6.55	0.942
187	9.5	9.6	0.99
234	11.4	10.8	1.055

Mean ratio 1.013

Having regard for the difficulty of keeping the conditions constant, the mean agreement between the observed and calculated values is satisfactory.

II. Waterflow constant, magnetic field varied.

(i) Change of magnetic field 1000 lines per square centimetre.

Polarization	With field on	Difference in millivolts
0.0	1.9	1.9
1.0	2.9	1.9
0.0	1.6	1.6
2.3	4.3	2.0
1.8	3.2	1.4
2.7	4.5	1.8

Mean 1.76

Calculated voltage = $(1000 \times 1.3 \times 140) / 10^8 = 1.82$ millivolts.
Observed voltage/calculated value = 0.96.

(ii) Change of magnetic field, 1750 lines per square centimetre.

Polarization	With field on	Difference in millivolts
186.0	189.5	3.5
190.0	193.8	3.8
195.0	198.0	3.0
180.0	183.5	3.5
195.0	198.6	3.6
200.0	203.5	3.5
210.0	213.3	3.3
194.0	197.2	3.2

Mean 3.4

Calculated value = $(1750 \times 1.3 \times 140)/10^8 = 3.2$ millivolts.
 Observed value/calculated value = 1.09.

(iii) Change of magnetic field, 2500 lines per square centimetre.

Polarization	With field on	Difference in millivolts
192.4	197.6	5.2
164.2	168.7	4.5
170.7	174.9	4.2
170.2	174.3	4.1
175.0	179.4	4.4
180.1	184.6	4.5
		—
	Mean	4.5

Calculated value = 4.5 millivolts.

Observed value/calculated value = 1.00.

(iv) Change of magnetic field, 3500 lines per square centimetre.

Polarization	With field on	Difference in millivolts
0.0	6.2	6.2
0.0	6.3	6.3
2.0	8.1	6.1
10.0	16.0	6.0
20.0	26.8	6.8
30.5	37.0	6.5
35.4	41.5	6.1
		—
	Mean	6.3

Calculated value = 6.36 millivolts.

Observed value/calculated value = 0.99.

From these we have :

Field across stream	Obs.	E.M.F.	Ratio
1000 lines per sq. cm.	1.76	1.82	0.96
1750 lines per sq. cm.	3.4	3.2	1.06
2500 lines per sq. cm.	4.4	4.5	1.00
3500 lines per sq. cm.	6.3	6.36	0.99
			—
	Mean	1.002	

It can therefore be said that the electrical forces caused by the movement of a partial conductor such as fresh water

in a magnetic field agree as closely as the conditions of the experiments permitted with the exact statement of Faraday's law, as a consequence of which these voltages and their derived currents must exist in the sea wherever water moves under natural forces as shore or tidal waves or translation across the earth's magnetic field. The movements of waves, either vertical or horizontal, give rise to corresponding electric currents. When the motion is rapid, as in quickly flowing rivers, or due to forces such as ships' propellers, the voltages may be much higher, and in the sea, owing to its better conductivity, large currents may circulate. In the northern hemisphere the magnetic field is downwards. As a result of this, waves which break on eastern shores are electrically polarized in a direction N. to S., and there must be around the shores of Great Britain for instance a right handed circulation of electric currents, feeble it may be compared with the other great physical forces in the phenomena of the ocean, but not perhaps negligible as a stimulus in the life of shore forms—whether animal or vegetable. This electric current flows up the coasts of Holland and Germany and Denmark in the same direction as that followed by the gravitational tides, but has no connection with them. The currents near the surface of the sea during a heavy storm in which there is much actual translational movement of water must be large. The current density is independent of the length of the wave, depending only on its velocity. Thus in water of resistivity ρ ohms per centimetre cube moving with velocity v centimetres a second in a field of B lines per square centimetre, the current density is $Bv/\rho \times 10^8$ amperes per square centimetre. That across the water leaving the propellers of say the *Mauretania* at a speed of for example 1000 centimetres a second in deep sea with $\rho = 20$, and a field locally increased by the presence of the iron of the vessel to say, 1 line per square centimetre, is half a micro-ampere per square centimetre, or about half an ampere across the active vertical area of the track. The current from such a ship can be detected at a distance of several miles by exploring plates in the sea.

The electrical current flowing across the Mersey from Liverpool to Birkenhead during ebb tide is about 15 amperes per mile of river. So far as the physical generation of electric currents in water by the movement of fish or water is a factor in their communication of alarm or the reverse, we are lead to the conclusion that it is not improbable, and that in any case there must always be in the sea near the shore weak electrical currents the existence of which appears to have been hitherto overlooked.

I desire to thank Professor Thornton for his constant help and advice, and for affording me the hospitality of his laboratory and apparatus.

ELECTRICAL PERCEPTION BY DEEP SEA FISH.

BY W. M. THORNTON, D.SC., D.ENG.

1. *Introduction.*

The means by which deep sea fish, many of them blind and all carnivorous, obtain food and avoid capture is still an unsolved problem. In the search for a solution it is necessary to examine every hypothesis which has a reasonable scientific basis, though by the nature of the case no such hypothesis can advance beyond a theory. The meaning of the abnormal development of the mucous glands of deep sea fish can only be found if they are shown to contribute to the reception of impulses necessary for the preservation of the species. In this paper the hypothesis is advanced that the glands of the lateral line of fish in general are their chief organs of directional perception. They are known to be sensitive to mechanical vibrations, and have been shown also, by Mr. Regnart, to be remarkably sensitive to electric currents. They control entirely the direction of movement of a fish in response to electrical stimulus; and since fish in movement set up electrical pressures, whose magnitude is known, it seemed worth while to examine whether the lower limit of current which induces response under experimental conditions is of the order of that occurring in nature. There is found to be a gap between them, but it is sufficiently small to warrant the presentation of these observations as a possible basis for further work on the subject.

2. *The Hearing of Deep Sea Fish.*

The physical features of great ocean depths are immense pressure, complete darkness and still water, but not perfect silence, and the low frequency vibrations of earth movements there are certainly transmitted to the water above. The mucous canals of fish have been regarded by some¹ as sense organs adapted to perceive such vibrations of water at wave lengths too great to be perceived by the ear.

The auditory nerves of most of the deep sea fish are perfect, and their hearing is probably as well developed as that of shallow-water fish. Since in quiet waters engine sounds of passing steamers are heard at distances of several miles by the simplest listening devices such as a rubber tube closed at the lower end and connected at the upper to a stethoscope, it is probable that on the main steamship routes depths of a few miles are relatively noisy, and that these sounds are heard there by fish.

Hydrophone observations made during the war with microphones and sensitive receivers gave no indication of audible sounds from moving fish though these could be clearly seen in the neighbourhood of the microphone. A faint rustling sound is reported to have been heard from a dense shoal of herring, possibly from broken water at the surface.

On the other hand, whales have been followed at night as steamships because of the similarity of their powerful heart beats, heard by underwater listening gear, to periodic engine sounds. If deep sea fish perceive one another at all by hearing, the pulsations heard are probably those made by the heart rather than any other movement. The displacement of water as a fish moves through it is not of the nature of sound, that is a pressure wave, but the change of movement of water as a blind fish approaches near to the walls of a tank would appear to be sufficient warning to it of the presence of a solid obstacle.

With regard to such movements of water Parker^a agreed with Schulze that the lateral organs might be receptors of low frequency vibrations, but Hofer^b maintained that they were receptors for stimuli due to differences in the velocity of water streaming past the body of the fish, presumably by differential pressures on the canals through the mucous. It has been shown^c that the lateral organs are not essential for the perception of low frequency vibrations, which are slow oscillatory movements of water, though the directional sense was much impaired by the elimination of these organs. It is certain that the lateral organs are sensitive to mechanical stimuli of various kinds,

but the high development of the lateral canal system in deep sea fish is not to be accounted for by such small mechanical differences. Gunther⁵ states that the extreme development of these canals in deep sea fish implies that they must perform in addition a function or functions other than those of fish in regions near the surface.

3 *The Phosphorescent Organs of Deep Sea Fish.*

Many deep sea fish are blind but are fitted with organs of phosphorescence. Since at these depths all fish are carnivorous, the purpose of phosphorescence in a blind fish is obscure, and is still an unsolved problem. There is, however, a close association between slime cells and phosphorescent organs, of which *Halosaurus macrorhynchus* is a good example.

Von Lendenfeld summarizes the properties of these organs as follows :

1. The phosphorescent organs of fishes are more or less modified glands, which have been partly developed from simple slime glands in the skin, and partly in connection with the slime canal system.
2. The typical clarate cells are modified gland cells.
3. The accessory reflectors and sphincters are developed from the skin around and below the gland.
4. The large suborbital organs are innervated by a modified branch of the trigeminus, and the other organs by the ordinary superficial nerves.

Authorities agree that the phosphorescent skin glands may be organs of perception, and the manner in which they are distributed along the lateral line and over the surface suggests that they are sensory points. Leydig, from the structure of the more highly developed glands, concluded that they were "pseudo-electrical" organs of perception, but did not offer any explanation of the means by which they were stimulated.⁶ Moseley, in discussing the great head organs of *Idiophis murrayi*, in which there

are hexagonal cells arranged in columnar masses with ordinary nerve fibres to each cell, concluded that they could not be electrical on account of the absence of the insulating connective tissue found between the cells of the electric fishes. The pressure in the latter may rise to 300 volts, and there must be insulation suitable for this. Organs of perception are under no such necessity. Stimulus of the order of a microvolt is sufficient to activate nerve, and if it can be shown that voltages of this minute order are set up by moving fish, the question of whether the phosphorescent glands are not after all electrical organs of perception is re-opened.

4. Electrical currents made by fish in their motion through the Earth's magnetic field.

Deep sea fish are not electrical in the sense that when at rest they are the seat of electromotive forces such as those of *Malapterurus* or *Gymnotus*, but all fish in motion are the source of such forces, for the following reason : When matter of any kind is moved, each electrical charge of which it is made up forms in itself a current around which there is a magnetic field. When the movement takes place in a magnetic field, these atomic fields react on the original field, and by this reaction the charges are caused to separate. An insulator becomes polarized, an isolated conductor has an "open circuit voltage."

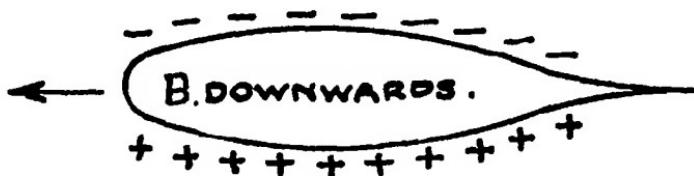


Fig. 1.

The polarity is such that the left-hand side of a body advancing into a magnetic field directed downwards becomes positive, the right-hand side negative. (Fig. 1.)

A fish moving relatively to the water by which it is surrounded forms part of an electric circuit of which half

the voltage is generated by its motion forwards and half by the motion backwards of the water propelled by it. (Fig. 2.)

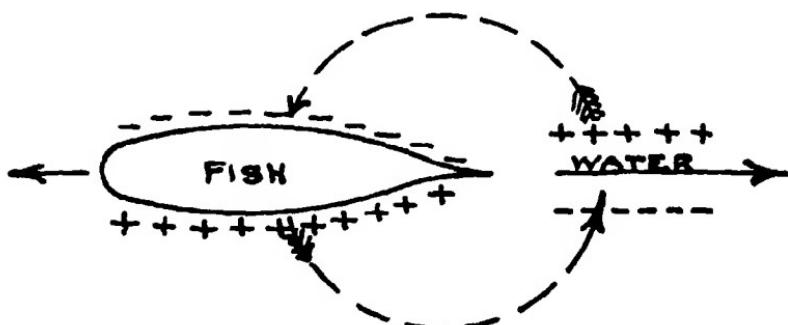


Fig. 2.

In the case of a ship these currents are large and can be readily detected, by exploring plates connected to a galvanometer, at distances of several miles, the propeller giving to them a characteristic low frequency pulsation by which a type of ship may be identified.

The electromotive force between opposite faces of a centimetre cube of matter, if not a perfect insulator, moving with velocity v centimetres a second at right angles to a magnetic field of B lines per square centimetre, is Bv in c.g.s. measure, or $Bv/10^8$ volts. Taking the earth's vertical magnetic field as 0.5 and the horizontal velocity of a quickly moving fish as 10 metres a second, each centimetre cube of its body becomes polarized laterally to a difference of $0.5 \times 1000/10^8$ or 5 microvolts. Between the opposite sides of such a fish 10 centimetres thick there is a total induced potential difference of 50 microvolts. The density of a fish is nearly that of water, thus in a given time it gives to a mass of water equal to its own a mean velocity equal to that with which it advances. The voltage of the circuit is then 100 microvolts.

The voltage due to the moving fish is divided between itself, the water and the receiving fish, if any. Let the

resistances of these be the same (a path of 2 metres long, 1 sq. cm. section, in sea water has a resistance of about 5000 ohms), then the voltage received by the second fish, assumed at rest, would be one third of that generated, or, in the above case, 33 microvolts.

5. *The Electrical Resistivities of Fish.*

In order to form an estimate of the total transverse resistance of fish the resistivities of parts of fish were determined by the Kohlrausch bridge at telephonic frequencies. Of these the following mean values are given :

<i>Muscle across fibres</i>	.	400	ohms per c. cube.
<i>Muscle along fibres</i>	.	230	" "
<i>Skin (2m., m. through)</i>	.	400	" "
<i>Slime</i>	.	115	" "
<i>Vitreous humour of eye</i>	.	120	" "
<i>Aqueous humour of eye</i>	.	136	" "
<i>Spherical lens (cod)</i>	.	290	" "
<i>Sea Water (coastal)</i>	.	25	" "

A fish 10 centimetres thick has a transverse resistance, including the skin, of about 4000 ohms per sq. cm. The current density due to its own motion (at 10 metres a

$$\text{second}) \text{ could not exceed } \frac{100}{10^4} / 4000 = 2.5 \times 10^{-8}$$

amperes per sq. cm., but the total current from a fish having, say, a half surface of 500 sq. cms. might be of the order of 10 microamperes. This current spreads out as from an electrical doublet, and would be picked up by another fish in the neighbourhood whether in motion or at rest. Experiment alone can decide whether currents of this order alarm fish when suddenly applied. If the skin of a fish were uniformly sensitive the total stimulus would be proportional to its area, but when, as Regnart has proved, the organs of the lateral line are so much more sensitive than the rest of the skin that when their nerves

are cut the fish does not respond at all directionally, it is necessary to consider the possibility of either (1) the concentration or gathering of electric currents in the water by the high conductivity slime leading them to the nerves of the gland (which, as previously pointed out, are branches of the sensory trigeminus), or (2) of the higher electrical sensitivity of the mucous gland canals and their contents, whether aided or not by extruded slime.

On the above argument, should the currents which cause response in fish, as indicated by their directional movements, prove to be of the order of 10^{-8} amperes per sq. cm., it would be certain that such fish could be aware of one another's movements, by the medium of the electric currents caused by their rapid motion through the earth's magnetic field, for currents of this order are not only possible but are a necessary physical result of such motion.

6. The Smallest Visible Electric Current.

Fish that live in shallow water have already, in the eye, an organ capable of detecting exceedingly small high frequency alternating electric currents. The energy in the least-visible light is about 0.06 microergs falling on a square centimetre a second,⁸ corresponding to $2 \cdot 10^{-11}$ ergs per cubic cm. of space in water. This energy is $4\pi i_0^2$, where i_0 is the maximum transverse current in a light wave.⁹ At the limit of visibility $i_0 = 4 \times 10^{-9}$ ampere per sq. cm. at right angles to the ray.

An estimate of the least rate of reception of energy may also be made from the facts¹⁰ that the least energy perceived by the whole retina is about 5×10^{-12} erg, and that the duration of the smallest visible electric spark is not greater than 10^{-4} secd. The least rate of reception is then $5 \times 10^{-12}/10^{-4}$ or about 0.05 microerg per second.

It has been shown to be possible that fish possess in their slime a medium not without influence on the reception of electric currents. The resistivity of slime, c.115 ohms per centimetre cube, is much lower than that of the skin. Slime therefore provides a relatively good conductor

(nearly four times better than skin and muscle) by which electrical currents in the water can be led into slime glands or canals in much the same way that Schulze regarded them as detectors of mechanical movement.

The conduction of a nerve impulse, though accompanied by electrical phenomena, is not a true electrical current. It has rather the nature of a wave of ionic instability, like that of a row of blocks in which one falling knocks down the rest in succession. The magnitude of the stimulus necessary to start such impulses in nerve is extremely small. The impulse begins by disturbing the equilibrium of potassium ions in the axis cylinder at an end plate or similar terminus, and the most direct way to do this is by leading in an electric current.

Electrical pressures of the order of a microvolt are found by the string galvanometer across points of section of nerve,¹¹ but this represents the full nerve impulse. Given a means by which pressures of that order could be applied through sense organs directly to nerve, it is certain that the stimulus would be strong enough to start the conduction wave to the brain. The structure of the hexagonal cells of the phosphorescent glands, for example, suggests that each of these adds to the nerve impulse, the effect being cumulative.

7. The Function of the Phosphorescent Glands.

Should the so-called phosphorescent glands be proved to be organs of electrical perception, there is a reason for their peculiar distribution. They are then sensitive regions the intensity of stimulus of which would give an indication of the direction from which currents came. Equal stimulus on each side of the fish would come from a source directly in front or behind; which of these would be indicated by the relative strength of response of the head or tail glands, not by any difference of time of reception, for induced electrical currents arrive at the same instant at every part of the surface of the fish.

Slime is phosphorescent. Light radiated from this

source, as from any other, is electrical in origin. It is an indication of an electrically sensitive state associated with chemical change. The phosphorescent gland is the seat of electrical action, and the ordinary nerves controlling the secretion are equally well adapted to receive electrical stimulus.

In the development of phosphorescent organs, the cell, at first open to the water, is closed by a translucent plug or lens, the resistivity of which may be about 290 ohms. This is lower than that of skin and muscle, and an organ with such a lens would still be a region sensitive to conduction currents. The thin transparent bony membrane covering the head organ of *Ipnotis* would, when moist, offer less resistance to the passage of electric current than these rudimentary lenses. Beneath the lens of the phosphorescent skin glands there is a thick slimy humour, and since, as Macallum argued, enclosure should not markedly interfere with the physical properties of a secretion, the resistivity of this humour might be expected to be near that of slime if they had the same origin. Taking the eye of a fish as the extreme form of an enclosed cell of this type with a vitreous humour, measurements made of the resistivity of many such humours gave a close average of 120 ohms per c. cube. That of skin slime is 115 ohms. There is, then, on the electrical evidence as well as the anatomy of the organs, some ground for the suggestion that the vitreous humour of the eye of a fish is a survival from a primitive slime gland. (In bullocks' eyes the resistivity of the vitreous humour has an average value of 83 ohms.

8. The Evolution of the Eye as an Electric Sense Organ.

The point of view indicated above is that the eye, the only organ of higher animals directly adapted for the reception of electrical currents, in the form of electro-magnetic light waves, may have arisen first from a slime cell, and that, as indicated by the order of its development in the vertebrate embryo, it is one of the oldest of the

organs, made to perceive the electrical currents present from all time near moving bodies in the parent sea. On this view the gland, secreting phosphorescent slime, becomes next an organ of phosphorescence closed by a translucent lens. Phosphorescence in itself is a secondary effect, useful to seeing deep sea fish in pursuit of prey, fatal to blind sea fish unless compensated by electrical sensory properties.

The high frequency currents that constitute light have themselves no direct effect on nerve other than by their heating action. In order to transform them into the unidirectional ionic change by which a visual nerve impulse is started, a photochemical reaction is interposed, that of the visual purple. This has not been fully worked out, but the fact remains that the bleaching of the pigment by light is a steady chemical change which gives a nerve stimulus in regular relation to the energy absorbed. The occurrence of pigmented cells in phosphorescent organs suggests that if these are in the first place organs of electrical reception the pigment there may be a substance chemically sensitive to electrical action and playing a part in the process of nerve stimulation.

If living forms began, as seems probable, on the sea-shore, deep sea forms can be regarded as modifications of surface types to suit the conditions of life there, with possible reversion to primitive function as detectors of electric currents in the case of organs such as those of sight, for which there is little use in darkness. The fact that many deep sea fish have vision shows either that their appearance there is relatively recent or that there is sufficient luminosity from phosphorescence to have prevented complete extinction of the function.

On the general question of the electrical properties of nerve it might be held that the very existence of the complex electrical network of nerves by which external stimulus is transmitted from the sense organs is itself conclusive evidence that it arose and was developed under circumstances in which perception of, or response to, electrical stimulus was the first condition of life, and the

fact that the electric current in the least visible light is of the same order, or less, than that made by the movement of fish, brings the latter into the region of possible sensory effects.

9. Conclusion.

Most of the above notes were first written some thirty years ago, when the generation of electric currents by moving fish first occurred to me. They were added to after the War, but have been awaiting experimental work on the sensitiveness of fish to electric currents. Measurements of the lower limit of perception of such currents by fish have been made recently by Mr. Regnart in the Electrical Engineering Laboratory of Armstrong College and at the Marine Laboratory, Cullercoats, which prove that fish exposed to light and accustomed to noise respond to currents of the order of 2 to 20 microamperes per sq. cm. when first applied, though they rapidly become used to them. The gap between the observed value of 2×10^{-6} and the current calculated from moving fish, which may be of the order of 2×10^{-8} through skin and muscle, can be partly bridged if we regard the slime which projects from a gland as an elongated conductor or antenna; an electrical collector which leads the currents in the sea through the fish by a path which forms a better conductor than skin does, though this only accounts for a 4 to 1 increase of sensitivity and there is still an unbridged gap between observed and estimated values.

In the relative quiet and complete darkness of the great ocean depths it is not improbable that fish are even more sensitive to stimulus, but the extremely small currents which have already been proved to activate fish show that the suggested action of the generation and perception of electric currents by them is perhaps worthy of consideration as an explanation of the hitherto unsolved problem of the means whereby blind deep sea fish perceive their prey or avoid capture. In this process it is now suggested that the currents generated by moving fish may be led into the organs of perception, which are either the

skin glands or the more specialized head organs, by means of the higher electrical conductivities of the slime, or possibly by the sensitive tissues of the mouth. Experiments on the response to weak electric currents of fish kept in complete quiet and darkness are desirable in order to see whether the observed limit may be still further lowered.

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- ¹ See F. E. Schulze, *Challenger Reports*, Vol. XXII, p. 311.
- ² G. H. Parker, 1905, *The Function of the Lateral Line Organs in Fishes*. Bull. U S Bureau Fisheries 24.
- ³ Hofer, 1908, *Studien über die Hautsinnesorgane der Fische*. Ber. Kgl. Biol. Versuchsstat. München.
- ⁴ H. C. Regnart, *Proc Univ Durham Phil Soc*, Part I, Vol VIII, 1928.
- ⁵ *Challenger Reports*, Vol. XXII.
- ⁶ F. Leydig, *Die Augendähnlichen Organe der Fische*. Bonn E. Strauss. 1891.
- ⁷ Professor H. N. Moseley, *Challenger Reports*, Vol. XXII, Appendix A.
- ⁸ Thornton, *The Eye as an Electric Organ*. *Phil Mag*, October, 1910, p. 563.
- ⁹ Jeans, *Electricity and Magnetism*, p. 611.
- ¹⁰ Bayliss, *Principles of General Physiology*, p. 522.
- ¹¹ Bayliss, *Principles of General Physiology*, p. 386, fig. 106, by Einthoven.

AROMATIC ELECTRONICS.¹

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INTRODUCTION.

At several previous lectures on the subject of the application of modern electronic theories to aromatic chemistry, the question has frequently been asked, "What is the gain over the older valency-band explanation of phenomena?" A very simple answer is forthcoming when the problem of the further substitution of mono-substituted benzene derivatives is considered, but before dealing with this question a brief introduction must first be given to the theories themselves. The latter are mainly due to the pioneering conceptions of Lapworth and Robinson (see *inter alia*, J.C.S., 1922, 121, 416, 427) on the one hand and, latterly, to Ingold on the other, each of whom has had the experimental assistance of a host of collaborators.

At the outset it must be emphasized that only qualitative generalizations are to hand, although from the masterly exposition by Robinson (see Allan, Oxford, Robinson and Smith, J.C.S., 1926, 401) of the rules to be followed, the effect of a group under given circumstances may be forecasted with reasonable probability. The following factors, in order of diminishing importance, are held to determine the result of a reaction :

- (1) The circumstances of the reaction—especially whether the reagent is anionoid or kationoid.
- (2) The conjugated systems.
- (3) The general electropolar effect of attached groups.

The rôle of the reagent itself cannot be too strongly emphasized, since in many cases (see later) it determines the possibility of the reaction, i.e. it is the prime agent. Most of the work in this field has been carried out with

¹ "The Eleventh Bedson Lecture."

kationoid reagents, e.g. nitric acid, which in its activated state is polarized as $\text{HO}^- \text{NO}_2^+$, and the halogens, $\text{Cl}^- \text{Cl}^+$, $\text{Br}^- \text{Br}^+$, and in consequence these will seek anionoid centres of activity in the benzene ring, viz., negative carbon. Such reactions also readily occur, because anionoid carbon appears to be the less natural state, and therefore the more reactive, positive carbon being the more natural or stable condition. An example, however, will be given later of attack on positive carbon by an anionoid reagent.

The conjugated systems are of course responsible for the so-called *alternating* or *conjugative* effect (termed by Ingold, *tautomeric* effect, and styled as $+T$ or $-T$ as the case may be. See more especially Ingold and Shaw, J.C.S., 1926, 2918).

In connection with the general effects of groups, whether they tend to repel or attract electrons, Ingold has made use of the very concise terms "source" and "sink," and their static effect has been divided by him into two functions, viz., a *direct effect* (D) exerted over space, and an *inductive effect* ($+I$ or $-I$ for source and sink respectively) relayed from atom to atom. The total effect of any group can therefore consist of at least four components, viz., (1) the dynamic alternating (tautomeric) effect due to actual electron displacements, and largely dependent on the demand of the reagent, (2 and 3) the direct and inductive effects, and (4) the steric effect which may be regarded as a volume effect but whose real origin is probably electrical.

The general effect of a group, in the absence of a reagent (the reagent may reinforce or even reverse the effect) may tend to exert more or less control over the covalency electrons binding it to the carbon atom; in the former case, e.g. with the nitro-group, by imposing a restraint, whereby the whole of the neighbouring carbon system may be deactivated; in the latter case by imposing a repulsion (release), e.g. with the methyl group, whereby the neighbouring system may be activated. Both these

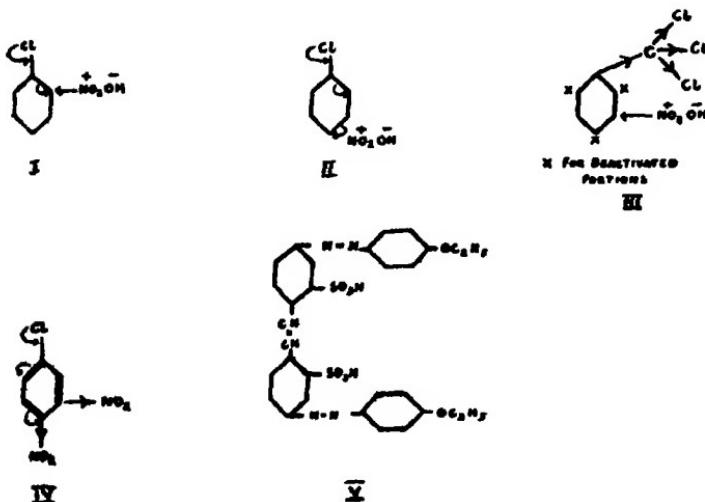
effects for the case of the benzene ring are manifested at the o- and p- carbon atoms, so that o-p- effect > m, either in a less or greater activated sense. On the other hand, the direct (field) effect, which groups exert over the molecule spatially, is of the same sign as the general (inductive) effect, but since it follows the Coulomb (inverse-square) law, the order of intensity will be o > m > p.

The opening question can now be answered, viz., that a group which produces an o-p activating effect, facilitates substitution in the o-p positions by a kationoid reagent; conversely, an o-p deactivating group inhibits o-p substitution by a kationoid reagent. The opposite should hold for anionoid reagents, but reaction is for this case far more difficult, due to the very inferior reactivity of positive carbon. In all cases the meta-position is relatively unaffected, so that in the activating case only o-p reaction occurs, and, in the deactivating case, only meta reaction can occur and this with difficulty, because the reagent itself must be sufficiently powerful to compel reaction to take place. When conjugated systems exist, the alternating (+T) effect overwhelms any purely general effect due to a group, e.g. in the further nitration of m-nitrotoluene, some 3:5-dinitrotoluene would certainly be expected on the older substitution theories (e.g., Crum-Brown), whereas in practice none is produced, since the o-p activating CH₃ group alone influences the positional attack, the NO₂ group exerting a purely deactivating effect which only influences the respective yields of the (o-p to the CH₃ group) nitro-products.

Another important feature of the electronic theory is that on the approach of a kationoid reagent, all groups containing lone-pair electrons (e.g. F, Cl, OCH₃, NHAc) are able to supply in varying degrees of freedom, a negative charge to the o-p carbons which thus become activated. A group like F or Cl therefore, which tends to ionize wherever possible, i.e. to acquire a negative charge, will thus act in a static sense (e.g. in a dyestuff) as an electron-sink, but in a reaction with a kationoid reagent

as an electron-source [e.g. in chlorobenzene (I)]. When the halogen is removed from the nucleus however, as in benzotrichloride (III), the sink-effect operates with consequent deactivation of *o*-*p* positions and resultant meta-nitration. Such a result could not be predicted on the older valency-band theory.

An interesting example of combined effects arises in the further nitration of *m*-chloronitrobenzene. Here the effect of chlorine is +T - I (Ingold and Shaw, *loc. cit.*), T > I, and since T operates by the alternating effect, whereas I decreases with distance (particularly with difficulty of passage through double bonds), T - I will be greater at *p*- than at *o*- position [e.g. in the nitration of chlorobenzene, much more *p*- than *o*- chloronitrobenzene (70 : 30 approx.) is produced, whereas with toluene, where +I (or +T + I, if alternating effects occur. See Lapworth and Robinson, *Mem. Manchester Phil. Soc.*, 1928, 72, 47) is greater at *o*- than at *p*- position, there is consequent predominance of ortho-nitration (57 : 40). A consequence of the concurrent deactivating effect



(-I - T) of the nitro-group is that the entire yield is chloro-3 : 4-dinitrobenzene (IV). On treatment with

caustic alkali, it is the 3-nitro-group which is replaced by hydroxyl and not the chlorine atom as would normally be expected, and this is due to the fact that the strain imposed by the 4-nitro-group is partially relieved by the chlorine atom, whereas the 3-nitro-group is attached to a carbon already very much constrained (i.e. rendered more kationoid) by the combined general effects of the chlorine and 4-nitro-groups, and therefore most prone to anionoid attack.

APPLICATION OF AROMATIC ELECTRONICS TO THE O. N. WITT CHROMOPHORE THEORY.

The first recorded observation on the relationship between colour and constitution was made by Graebe and Liebermann in 1868 (Ber. 1, 106). These chemists pointed out that all the known coloured organic substances became colourless on the addition of hydrogen, and they arrived at the conclusion that such colour was due to unsaturation, e.g. quinone, azobenzene, rosaniline. The next recorded observation was by O. N. Witt in 1876 (Ber. 9, 522), who brought forward his theory of chromophores and auxochromes. The nomenclature of this theory is still largely used, and the theory itself also is still recognized as a valuable, if somewhat superficial relation, between colour and constitution. Witt pointed out that two things are required to give an organic substance colour and dyeing properties. The molecule must possess a certain grouping of atoms to give it the potentiality for colour, and it must also possess a salt-forming radicle to bring out the colour and dyeing properties. The potential colour groups, e.g. NO_2 , $-\text{N}=\text{N}-$, $-\text{C}=\text{O}$, were termed "chromophores," and the molecules containing them "chromogens," e.g.



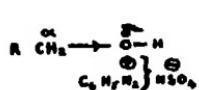
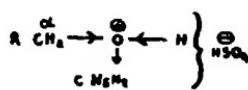
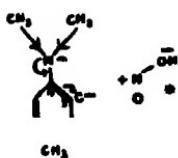
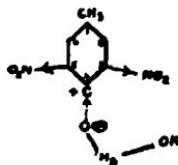
be noticed that some of Witt's chromogens are colourless, e.g. nitrobenzene, whilst others have a feeble colour, but none of the chromogens has any dyeing property. The

colour is developed or strengthened by the salt-forming groups called "auxochromes," e.g. —OH, NH₂, and substituted NH₂. Not all salt-forming groups, however, can act as auxochromes, e.g. —SO₃H, COOH, and the electronic theory for the first time furnishes the discriminating explanation for this division of salt-forming groups. Since colour is due to absorption of photo-energy by the molecule—the tighter the electronic framework, the higher the wave-lengths absorbed and the redder the colour; conversely, the less restrained the system, the lower the wave-length absorbed and the bluer the colour. Sink groups produce the former effect, sources the latter. Now of the salt-forming groups mentioned, the hydroxyl and amino-groups are electron-repelling (source) (o—p directing) and consequently increase the electronic mobility of the system with blueing effect on the colour, and, most important for the dyeing process, with increased activation of the molecule as a whole, so that it can more readily unite with a textile fibre. On the other hand, the sulphuric and carboxyl groups both impose restraint on electrons (i.e. are meta directing) with consequent inhibition of molecular activity and prevention of fixation by the fibre. This argument will hold good whether dyeing is the result of chemical or physical processes. The auxochrome effect is consequently something distinct from the salt-forming property, a fact which finds exemplification in the dyestuff Chrysophenine (V), which has no auxochrome in the O. N. Witt sense. However, since Meyer, Irschick and Schlösser (Ber. 1914, 47, 1741) found that a sufficiently active diazonium salt such as diazotized 2 : 4-dinitro-aniline will couple with β -methoxynaphthalene, it follows that the methoxyl-group here and the ethoxyl-groups in Chrysophenine can be made to function as auxochromes (activating agents), in the former case by the diazonium reagent and in the dyestuff case, *per se*, in the sense of producing the requisite electronic mobility. The search for new auxochromes should in consequence of this viewpoint receive a fresh stimulus, now that their true characteristics as electron-activators is recognized.

It may be objected that the $-COOH$ and $-SO_3H$ groups are present in the dyestuffs as sodium salts and therefore in the dyebath as negative ions, but it must be remembered that acid assistants are added to the bath and that the actual union in the case of wool is between the fibre and the free dyestuff acid.

THE DECOMPOSITION OF DIAZO SALTS BY ALIPHATIC ALCOHOLS

Although this decomposition constitutes a well-known method for the replacement of the diazo-group by hydrogen, nevertheless in many cases the reaction products include alkyl ethers sometimes exclusively. The dual character of the decomposition process has been explored by means of a reaction between benzene diazonium sulphate on the one hand and the series methyl, ethyl, n-propyl, isopropyl and n-butyl alcohols on the other, i.e. with the simplest of materials. The reaction was followed by the amount of aldehyde formed since every molecule of benzene produced during replacement of hydrogen is accompanied by one molecule of an aldehyde which in turn was estimated by means of its p-nitrophenylhydrozone

VIVIIVIVIIVIII

The mechanism of the reaction can be electronically envisaged as follows. Firstly the formation of a complex between the alcohol and the benzene diazonium sulphate in which the union may be purely electrostatic or dative (VII), and secondly scission of molecular (VI) nitrogen.

which involves an appropriation of two electrons either from the phenyl group or from the oxygen. In the former case, the phenyl group will be left with a positive carbon atom which will then unite with the potentially anionoid oxygen to form an alkyl ether; in the latter case the oxonium oxygen will ionize one of the hydrogens attached to the α -carbon atom and this will combine with the phenyl group which has been left with one negative carbon atom, the alcohol being thus converted into an aldehyde. When the diazonium salt is unsubstituted, then both reaction products appear except in the case of methyl alcohol, which yields anisole only. With substituted diazonium salts the general effect of the substituent plays a most important part according as to whether it is + I or - I, viz.: when + I, as in the case of toluene diazonium salts, then only ether formation occurs (Bramwell, Amer. Chem. J., 1897, 19, 561; Alleman, *ibid.*, 1904, 31, 24; Roberts and Alleman, J. Amer. Chem. Soc., 1911, 33, 391) because appropriation from the phenyl group is facilitated; when - I, as in the nitrobenzene diazonium salts, formation of hydrocarbon and aldehyde predominates (Orndorff and Cauffmann, Amer. Chem. J., 1892, 14, 45; Orndorff and Kortright, *ibid.*, 1891, 13, 153) because appropriation of electrons from the phenyl group is inhibited.

Keeping the simple unsubstituted diazonium salt and employing the alcohol series above, it follows from electronic theory that the oxygen atoms in the alcohols are progressively activated from methyl to n-butyl, so that the ionization ability of the α -carbon hydrogen atoms will be progressively diminished, with the result that a regular decreasing amount of aldehyde formation should ensue. The data obtained are in entire agreement with this standpoint: CH_3OH (0), $\text{C}_2\text{H}_5\text{OH}$ (9.4), $n\text{-C}_3\text{H}_7\text{OH}$ (4.7), $iso\text{-C}_3\text{H}_7\text{OH}$ (5.0), $n\text{-C}_4\text{H}_9\text{OH}$ (1.3) (the numbers represent mol. per cent. aldehyde per mol. amt. of benzene diazonium sulphate taken), except for methyl alcohol, which should give the maximum amount of aldehyde. This behaviour of methyl alcohol is regarded as entirely anomalous and is ascribed to the symmetrical configuration of the three

methyl hydrogen atoms. To test this viewpoint benzyl alcohol was employed, a product which is derived from methyl alcohol by replacement of one hydrogen by the phenyl group whose general effect (- I), $C_6H_5 \leftarrow CH_3OH$, is the opposite of that due to the methyl group in ethyl alcohol (+ I), $CH_3 \rightarrow - CH_2OH$; consequently aldehyde formation should be much greater, as proves to be the case, viz., 19.5. The series of substituted methyl alcohols thus exhibits continuity with the sign of the general effect.

NITROUS ACID AS A NITRATING AGENT.

Nitrous acid *nitrates* dimethyl-p-toluidine, giving at least 80 per cent. of 3-nitro-dimethyl-p-toluidine (3-nitro-4-dimethylaminotoluene); nitric acid at the same dilution is practically inactive. O-nitrosation analogous to the p-nitrosation of dimethylaniline does not appear to take place. Since 2-nitro-dimethyl-p-toluidine is produced by the normal nitration process, the mechanism of the above reaction must differ from that of ordinary nitration.

Lapworth and Robinson (*loc. cit.*) explain the apparently anomalous o-nitration of benzaldehyde and of acetophenone by assuming the formation of an additive complex (VIII) of nitric acid and the unsaturated group, which then favours nitration in o-position. In the light of this conception, it may be assumed that the nitrogen atom and the 3-carbon atom of dimethyl-p-toluidine, which are both strongly activated, produce a negative field which attracts the polarized nitrous acid, $H\bar{O}NO^+$, and, by rendering the nitrogen* (IX) less positive, makes it prone to oxidation; the free nitrous acid in the solution then oxidizes the nitrous acid component of the complex to nitric acid with evolution of nitric and nitrous oxides and subsequent nitration at the activated 3-carbon atom.

AN EXAMPLE OF AN ANIONOID REAGENT SEEKING A KATIONOID CENTRE.

The mobility of the chlorine towards anionoid reagents in o- and p-chloronitrobenzenes afford well-known

examples of anionoid attack at kationoid carbon, but the cases of anionoid reagents seeking kationoid C—H centres in benzene derivatives are rare. Such a case arises when a suspension of 3:5-dinitrotoluene in aqueous sodium hydroxide is boiled with freshly precipitated mercuric oxide, when 3:5-dinitro-p-cresol is obtained in approximately 50 per cent. yield, the other reaction products being amorphous irresoluble complexes mixed with metallic mercury. Since mercuric oxide in the absence of sodium hydroxide has no action upon 3:5-dinitrotoluene, whilst sodium hydroxide alone gives no such simple hydroxyl product as the above, it is concluded that the strongly kationoid 4-carbon atom (X) produced by the combined $-I$ effects of the nitro-groups has been attacked by an anionoid mercurate ion, which first forms the unstable complex (X), this subsequently decomposing to give 3:5-dinitro-p-cresol.

NEW BANDS IN THE S₂ SPECTRUM.

By W. E. CURTIS, D.Sc., AND S. TOLANSKY, B.Sc.

The absorption and fluorescence spectra of diatomic sulphur vapour have been analysed, so far as vibration structure is concerned, by Rosen.¹ Together they form a very extensive system stretching from 4540 Å. (22,000 cm.⁻¹) to 2380 Å. (42,000 cm.⁻¹). The range of vibrational quantum numbers involved is 0 to 37 for v' and 0 to 25 for v'' , and the intensity distribution is of the normal (Condon) type characteristic of an electron transition giving rise to a considerable change of nuclear separation. The fluorescence system includes many more bands than occur in absorption, but on account of their faintness the measurements are rather inaccurate, errors of ± 15 cm.⁻¹ being fairly common, and there is doubt in some cases as to whether the $v'v''$ allocations are correct. Quite recently Naudé and Christy² have reported the results of an investigation of the S₂ emission and absorption bands using much greater dispersion than Rosen's, which allowed of a rotational analysis in the case of several bands. They are in general agreement with his analysis, and conclude from the rotational structure that the electronic transition is of the type ${}^3\Sigma \rightarrow {}^1\Delta$, giving three P and three R branches. They also note the occurrence of a number of perturbations and have been able to study the development of predissociation in some detail. Their analysis is complete except for a number of weak satellite heads found mainly in absorption; further reference to these will be made later. Their observations cover the region 2400 to 5300 Å. Since ours, although made with relatively small dispersion, extend up to 8000 Å., it seems worth while to record briefly such of the results derived from them as will not be obtainable from Naudé and Christy's work.

The source used was a Pyrex tube 20 cms. long and 2 cms. in diameter, with external electrodes connected to a circuit in which oscillations of frequency about 20

pressure in the tube was taken down as far as possible with an oil pump and charcoal cooled in liquid air, and sulphur was distilled in from a side tube. It was necessary to heat the tube to start the discharge, and the maximum brightness was attained when it was kept at a temperature of about 250° C. Nothing but S₁ bands could be detected in the spectrum. Photographs were taken on two spectrographs, a Hilger constant deviation instrument and a Hilger large quartz El, the latter alone being used for wave-length determinations, which extend to 6610 Å. Faint bands evidently belonging to the same system were obtained on extreme red plates with the smaller instrument, but the dispersion was insufficient to permit of analysis. The wave-numbers listed are probably accurate to within a couple of wave-numbers in the case of sharp heads, but frequently overlapping introduces much more uncertainty than this. Nevertheless the data are considerably more reliable than those previously available. This is probably due not only to the larger dispersion employed but also to the fact that Rosen's data refer mainly to fluorescence lines, which may occur anywhere in the band to which they belong. Further, the fluorescence was composite, resulting from excitation by several lines simultaneously.

The relatively simple appearance of the spectrum above 5000 Å. is to a certain extent spurious, since it is partly due to the fact that in this region the ratio of the two vibration frequencies ($\omega' \approx 400$, $\omega'' \approx 600$) is very nearly 2 : 3, so that for example the bands (v', v''), ($v' + 3, v'' + 2$) and ($v' - 3, v'' - 2$) are approximately superposed. Fortunately the progressions are rather short or the analysis would have been much more difficult and uncertain.

The wave-lengths, wave-numbers and intensities of the heads measured are given in Table I; the $v' v''$ allocations are also indicated. A set of weaker heads running roughly parallel to the main system has been identified and analysed in a similar manner. The vibrational quantum numbers attributed to these are in italics. The intensities are visual estimates.

TABLE I.
DETAILS OF S₁ EMISSION BANDS.

λ	ν	Int.	$v' v''$	λ	ν	Int.	$v' v''$
4832.9	20685.7	2	0, 17	97.1	547.8	4	4, 25
42.1	646.6	10	0, 17	5702.1	532.5	3	—
87.1	456.3	3	1, 18	10.1	508.0	8	4, 25
4935.1d	257.1	3	2, 19	28.6	451.4	4	1, 23
80.2	073.9	4	0, 18	61.1	352.9	1	5, 26
89.5	036.5	8	0, 18	69.5 *	327.7	5	2, 24
5036.2	19850.8	4	1, 19				5, 26
90.2d	640.2	5	2, 20	83.4 d	286.1	3	2, 24
5135.4	467.2	2	0, 19	5826.9	156.9	3	3, 25
45.4	429.5	4	0, 19	31.5	143.5	2	6, 27
92.0	255.1	2	1, 20	40.6	116.6	9	3, 25
94.2	246.9	9	1, 20	87.2	16981.3	4	4, 26
97.4	235.0	6	4, 22	5900.7	942.3	9	4, 26
5241.0	075.2	3	2, 21	53.6 d	791.9	2	5, 27
49.7 d	043.4	8	2, 21	62.2 d	767.8	6	5, 27
91.8 d	18891.9	1	3, 22	80.8 d	715.5	2	2, 25
98.7 d	867.5	1	0, 20	6025.4*d	592.0	2	6, 28
5303.8 d	849.1	2	3, 22				3, 26
09.2 d	829.8	4	0, 20	39.1 d	554.1	7	3, 26
58.4	664.1	2	1, 21	87.4	422.9	3	4, 27
59.0	655.0	6	4, 23	90.6 d	414.4	2	7, 29
5407.7	487.0	4	2, 22	6102.3	382.8	5	4, 27
18.8	449.0	8	2, 22	55.5 d	241.2	1	5, 28
80.8	307.1	3	3, 23	65.8 d	213.9	5	5, 28
65.2	292.5	3	—	6234.5 d	035.4	1	3, 27
70.1	276.3	2	—	50.2 d	15995.0	3	3, 27
72.8	267.1	9	3, 23	98.0 *	871.5	2	7, 30
5516.9	121.2	2	4, 24				4, 28
21.3	106.7	1	—	6315.6	829.5	3	4, 28
30.0 *	078.2	6	{ 4, 24 1, 22	71.1	691.7	1	5, 29
42.7	036.8	4	1, 22	80.7	667.9	3	5, 29
83.8	17903.9	4	2, 23	6411.4	592.9	0	2, 27
94.1 d	871.1	3	—	56.6	483.8	0	3, 28
96.4 d	863.7	5	2, 23	74.3	441.5	1	3, 28
5639.3	727.9	4	3, 24	6524.8 d	322.0	1	4, 29
5643.5	17714.5	3	—	42.3	281.0	2	4, 29
51.6	689.2	10	3, 24	99.7	148.1	0	5, 30
				6609.9 d	124.7	1	5, 30

The analysis of the system into vibrational progressions is set out in the usual manner in Tables II and III. No attempt has been made to derive the positions of the band origins from those of the heads, as the consequent errors are certainly less than those of measurement. Rosen's v' and v'' values have been adopted, since Naudé and Christy have found them to be substantially correct. Of the 41 bands of the main system listed in Table II about 17 at the short wave-length end have already been recorded by Rosen. The low accuracy of his measurements sometimes renders identification doubtful, however.* The weaker system given in Table III is entirely new, but the order of accuracy of the wave-numbers is somewhat lower than for the main bands.

Considering first the main bands, the lower state differences (ω') are seen to be fairly regular, with a second difference of 61 (cf. Rosen, 5·8). The upper state differences show marked irregularities, however. Those occurring for $v' = 0$ and $v' = 1$ may possibly be due to some extent to wrong identifications, but the values from $v' = 2$ to 5 appear to be well established. The mean values are 401·9, 388·4 and 385·4, and since none of these is likely to be in error by more than about one unit it is evident that a marked perturbation must exist. This does not appear to be confined to one level only, or it would show itself as an equal and opposite effect on two successive ω' values only. It is rather in the nature of a definite break in the $\omega' v'$ curve in the neighbourhood of $v' = 5$, but the observations for lower v' values are not sufficiently numerous to establish its precise nature with certainty. No doubt this is one of the perturbations reported by Naudé and Christy as occurring among the levels of the upper electronic state.

A spectrogram of the portion of the system under investigation, with vibrational transitions indicated, is

Note added in proof.

* From the further data recently published by Naudé and Christy it appears probable that the v' and v'' values used here should be increased by 3 and 2 units respectively.

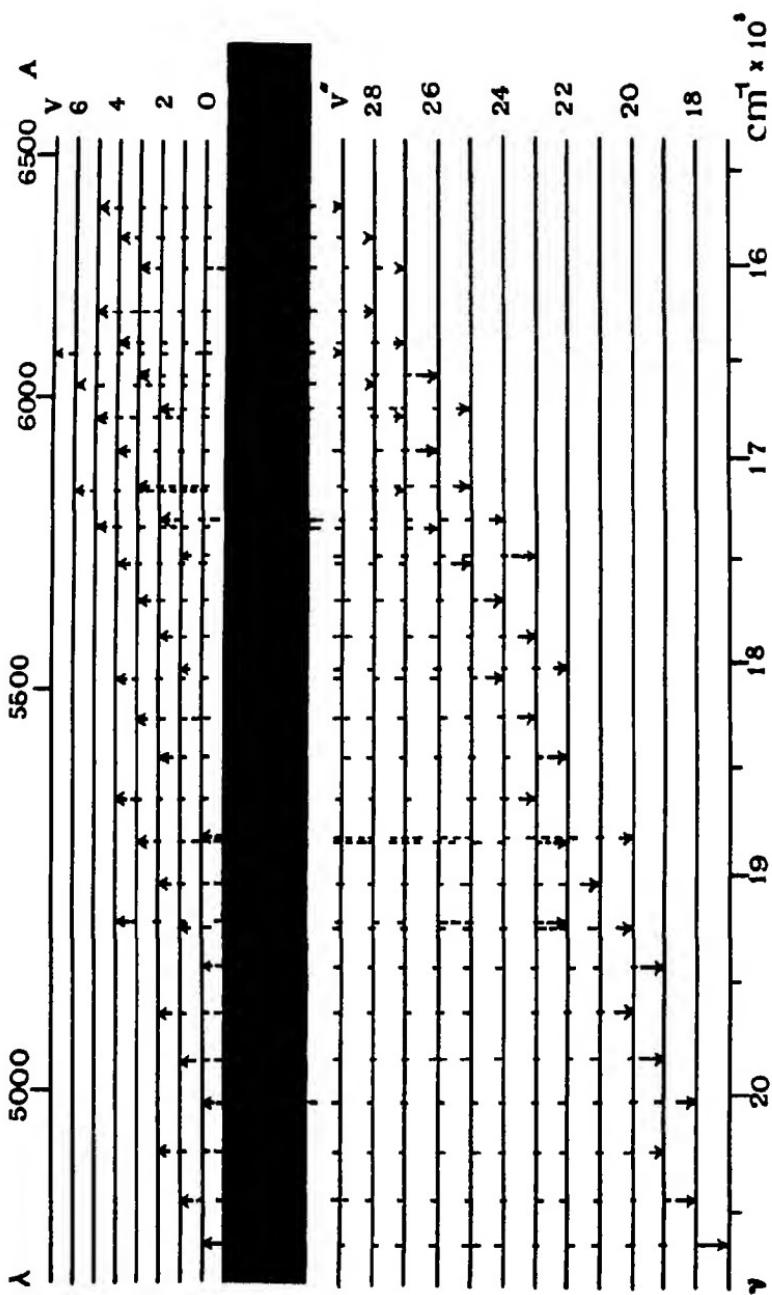
TABLE II
WAVENUMBERS OF STRONG S₂ HEADS

ν'	0	1	2	3	4	5	6	7	Mean $\bar{\nu}'$
17	20046 6								610 1
	610 1								
18	20055 5	419 8	20456 3						603 2
	607 4	605 5							
19	19439 5	421 3	19850 8	406 3	20257 1*				601 8
	599 7	603 9	616 9						
20	18839 8	417 1	19246 9	393 3	19640 2				596 8
			596 8						
21				19043 4					594 3?
			694 3						
22	18036 8	412 3	18449 1	400 0	18849 1	385 9	19235 0		
	585 4	585 4	582 0	580 0					583 2
23	17451 4	412 3	17863 7	403 4	18267 1	387 9	18655 0		
	577 6	577 9	576 8						577 4
24	17286 1	403 1	17859 2	389 0	18078 2*				
	570 6	572 6	570 2						571 1
25	16715 5	401 1	17116 6	391 4	17508 0				
	562 5	565 7							564 1
26	16554 1	388 2	16942 3	385 4	17327 7*				
	559 1	559 5	559 9						559 5
27	15592 9	402 1	15986 0	387 8	16382 8	385 0	16767 8	375 7	17143 5
	553 5	553 5	553 9	551 5					553 0
28	15441 5	388 0	16839 5	384 4	16213 9	378 1	16592 0*		
	546 5	546 0							547 2
29	15281 0	386 9	15667 9						16414 4
		543 2							542 9
30	15124 7								543 1
									16871 5*
31	419 4	412 3?	407 9	385 4	376 9		370 7		

TABLE III
WAVENUMBERS OF WEAK S₂ HEADS

	0	1	2	3	4	5	Mean ω'
v	17 20685 7	611 8					611 8
18 20073 9						606 7	
666 7							
19 19467 2							699 7
559 7							
20 18897 5 337 6	192365 1	591 9					591 0
21	18864 1	411 1	19075 2				
			688 2				
22	18078 2*	405 9	408 8	18487 0	404 9	18891 9	387 0
23	17903 9	403 2	18307 1				384 0
		583 1	584 8				
24	17327 7*	400 2	17727 9	383 3	18121 2		377 7
		577 0	579 2				
25		17156 9	390 9	17047 8			572 2
		554 9	566 5				
26		16592 0*	389 3	16891 3	371 6	17352 9	565 7
		556 6	558 4				
27		16035 4	387 5	16423 9	369 0	16791 9	538 7
		557 6	551 4				
28	15483 8	387 7	16871 5*	369 7	16241 2		551 2
		549 5	549 5				
29		15322 0	369 7	15891 7			
		543 6	543 6				
30	Mean ω'	387 6 ?	410 0	402 8	388 8	370 0	15148 1

Vibrational Transitions in the Band System of S_2



given in the Plate. The last seven bands in Table I do not appear in the reproduction, but are easily measurable on the negatives.

- Turning next to the question of the origin of the weaker bands given in Table III, two main possibilities present themselves, they may be regarded as a separate system or as companions to the heads of the stronger system. The results of the former treatment will be seen from Table III. The v' intervals are quite regular and closely comparable with those of the strong system, the mean difference (strong - weak) being only $+0.5 \text{ cm}^{-1}$. This clearly suggests that the two systems have a common lower level. Of the four well determined v' intervals three (410.0, 402.8, 388.8) agree satisfactorily with the corresponding intervals for the strong system (412.3?, 401.9, 388.4), but the next (370.0) is quite discordant (with 385.4). Each is the mean of four concordant values, so that the upper levels certainly cannot be common. It is worthy of note that the perturbation appears at the same place in both systems and is of the same order of magnitude, but in opposite directions. The discrepancy is also evident from a consideration of the separations of corresponding heads of the two systems, which are as follows (mean values)

$v = 0$	1	2	3	4	5
$\Delta v = 38.0$	41.4	39.9	40.0	40.8	24.8

The abnormality of spacing of the weak heads associated with the $v' = 5$ bands may readily be seen by reference to the Plate.

If the weak heads do not form an independent system their relation to the main heads might be one of the following types

(1) Satellite branches, corresponding to an effective change of rotational quantum number of -2 . The attribution of the main system to a ${}^2\Sigma \rightarrow {}^2\Sigma$ transition by Naudé and Christy seems to exclude this possibility, since such satellite branches would not be observed in bands of this type.

(2) Isotope effect. There are three isotopic sulphur atoms at present known, of masses 32, 33 and 34. The

relative proportions^a being approximately 96, 1 and 3. On this view, then, the strong heads would be due to the $S_{32}S_{32}$ molecule and the weak heads to the $S_{32}S_{34}$. The relative abundance of the two types would be $32^3 : 64$, or $16 : 1$. This ratio seems larger than the estimated ratio of intensities of strong to weak heads, but as no actual intensity measurements are available the possibility cannot be ruled out on this account.

The isotope separations to be expected in this region were calculated by the method given by Patkowski and Curtis,⁴ and range about 180 cm.^{-1} (weak - strong). This is much larger than the intervals given above, but a displacement of the same order (~ 220) is obtainable by associating the weak heads with the next strong head but one on the red side. Not only is there no numerical agreement with the calculated values but the observed separations are found to increase with v' for the same v'' , whereas the isotopic separations must of necessity decrease with increasing v' . We may therefore conclude that the weak bands cannot be due to the isotope effect. Moreover, it is evident from the calculations why the latter has not been observed, for it happens that all the $S_{32}S_{34}$ heads in this region would fall just inside $S_{32}S_{32}$ heads and thus be completely masked.

The most plausible explanation of the weak system would seem to be that it originates from a second electron transition, the lower level of which is the same as that of the strong system whilst the upper level lies about 40 cm.^{-1} higher than that of the latter. It would be premature to offer any opinion as to the possible nature of such an additional level until more extensive data are available, but it is of interest to note that Naudé and Christy mention "a number of weak satellite heads found mainly in absorption which are probably due to a different electronic transition."

The existence of a third electronic level is also indicated by the occurrence of predissociation effects in this spectrum, first noted by Henri.⁵ Naudé and Christy state that it sets in at $v' = 10$, which corresponds to an excitation energy of $36,110 \text{ cm.}^{-1}$. According to Kronig's theory⁶ this implies

that a third electronic level exists, of which the continuum probably begins in this region and which should not be capable of combining with the upper level of the main system. One would therefore expect that it would combine with the lower level and that possibly the weak system of bands might be due to this transition. The objection to this explanation is that the spacing of the upper levels of the two systems has been shown to be approximately the same, so that the continua of both should begin at about the same point, and therefore no interaction between them such as would lead to the observed predissociation should be possible.

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- ¹ *Zeitschr. f. Phys.*, 43, 69, 1927; 48, 545, 1928.
- ² *Phys. Rev.* 36, 1800, 1930.
- ³ *Roy. Soc. Proc., A*, 115, 504, 1927; and *Nature*, 117, 893, 1926.
The table in the former reference and also that in the article
'Isotope,' *Encyclopædia Britannica*, 14th ed., give 33 as more abundant than 34, but this appears to be an error.
- ⁴ *Trans. Faraday Soc.*, 25, 725, 1929.
- ⁵ *Structure des Molécules*, 1925, p. 92.
- ⁶ *Zeitschr. f. Phys.*, 50, 347, 1928.

A PRELIMINARY EXAMINATION OF THE MORPHOLOGY OF THE SOMATIC CHROMOSOME IN ROSA.

By J. W. HESLOP HARRISON, D.Sc., F.R.S., AND
K. B. BLACKBURN, D.Sc.

The study of the somatic chromosome in Rosa has been so overshadowed by the remarkable features revealed in the meiotic phase of the unbalanced polyploids that most workers in rose cytology have allowed the matter, important as it is, to remain in comparative obscurity. In fact the words of Hurst (1929), "In Rosa proper all the chromosomes are relatively the same in size and shape, though they differ remarkably in number," correctly represents the situation as it has appeared to most of us. Tackholm (1920, 1922), Blackburn and Harrison (1921, 1924), Erlanson (1929), and Hurst (1929), in giving figures of somatic plates in Rosa almost uniformly picture the individual chromosomes as more or less regularly curved sausage-shaped rods; nevertheless, a critical inspection of occasional figures demonstrates that the chromosomes are not quite so featureless as supposed.

Whilst, as already stated, the small amount of time devoted to a careful consideration of the somatic garniture accounts for their apparent lack of interest, other causes must be cited as contributing to this: (1) the choice for study of chance somatic mitoses in diverse tissues and irrespective of their situation and (2) the use of drastic fixatives like Carnoy's fluid which, in addition to destroying most cytoplasmic inclusions, obscures the structure of the individual chromosome, especially in somatic tissue. With the advent of new and more satisfactory fixatives, and the examination of standardized zones like the meristematic tissues of the root tips, the study of the morphology of somatic chromosomes has been revolutionized. Using root-tips, fixing with Langlet's modification

of Navaschin's Fixative, and staining with Iron Alum Hæmatoxylin as usual, we have systematically reviewed the somatic chromosome complements of selected species of *Rosa*, the species subjected to examination being *Rosa lutea* var. *punicea* Mill., *R. gymnocarpa* Nutt., *R. pisocarpa* A. Gray, *R. Soulieana* Crép. and *R. spinosissima* L.

Concerning these roses a few explanatory remarks seem necessary. By most authorities, who have ventured along the stony path of rose classification, including the latest (Herring 1925), *R. gymnocarpa* and *R. pisocarpa* are assigned to the Section Cinnamomeæ, *R. Soulieana* to the Synstylæ, *R. spinosissima* to the Pimpinellifoliæ and *R. lutea* var. *punicea* to the Luteæ. According to Hurst's (1927) classification, based on his differential septet system, *R. Soulieana* is an AA diploid species, *R. gymnocarpa* a BB diploid, *R. pisocarpa* a DD diploid and *R. spinosissima* as a BBCC tetraploid form. *R. punicea* Mill. he separates as a distinct subspecies from *R. lutea* Mill., and then classifies both as subspecies of *R. pimpinellifolia*. Erroneously, in our opinion, he assumes this latter to be differentiable from *R. spinosissima* and puts forward its septet formula as BBDD. Tackholm, working with plants from Upsala, also determines *R. lutea* var. *punicea* to be tetraploid.

On the other hand, as the upshot of our researches, *R. lutea* var. *punicea*, raised from seed kindly supplied by the Royal Botanic Gardens, Edinburgh, has turned out to be diploid. We are very far from assuming that the findings of other workers are incorrect, but content ourselves with stating that, at present, our plants give us no reason for looking upon them as other than *R. lutea* var. *punicea*.

DESCRIPTION OF THE CHROMOSOMES.

A glance at the figures in text figure A will exhibit the type of plates we secured for study. Needless to say, these plates are selected plates in which the chromosomes are favourably disposed for critical examination; many

other plates came under review, some of which only afforded us individual chromosome suitable for study, but always confirmed the results obtained from better plates.

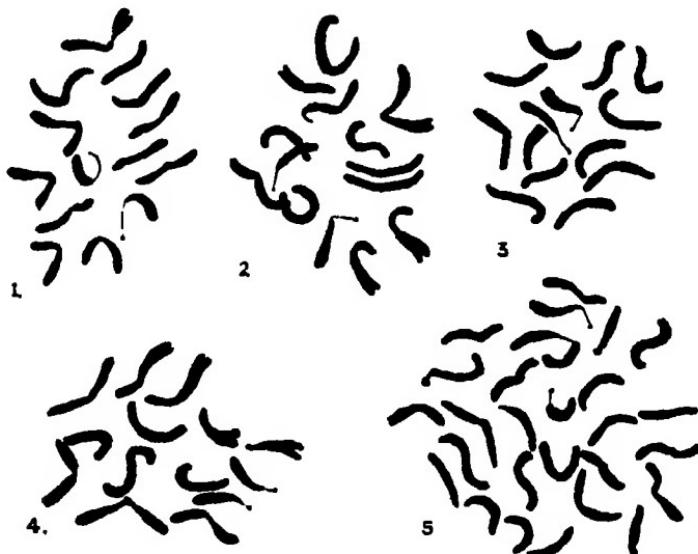


FIG. A

- | | |
|--|---------------------------|
| 1. <i>Rosa lutea</i> var. <i>punicea</i> | 4. <i>R. Soulieana</i> |
| 2. <i>R. gymnocarpa</i> | 5. <i>R. spinosissima</i> |
| 3. <i>R. pisocarpa</i> | |

The first point that strikes one immediately as quite new is the circumstance that chromosomes bearing satellites exist in all five¹ species. The number of such chromosomes in the diploid species is certainly two; of the state of affairs in *R. spinosissima* the most that we can say with absolute certainty is that there are two satellited chromosomes, and very possibly four. To emphasize these facts, and to facilitate further comparison, we present in text figure B an analysis of the various complements. In that figure, in the seventh vertical column appear the chromosomes endowed with satellites and, with the reservations made under *R. spinosissima*, we may label them as type VII.

¹ Satellited chromosomes have likewise been detected in *Rosa tomentosa* and certain of its hybrids.

Whilst the chromosomes of type VII may be described as substantially alike in *R. gymnocarpa*, *R. pisocarpa*, *R. Soulieana* and in the first pair and possibly the third

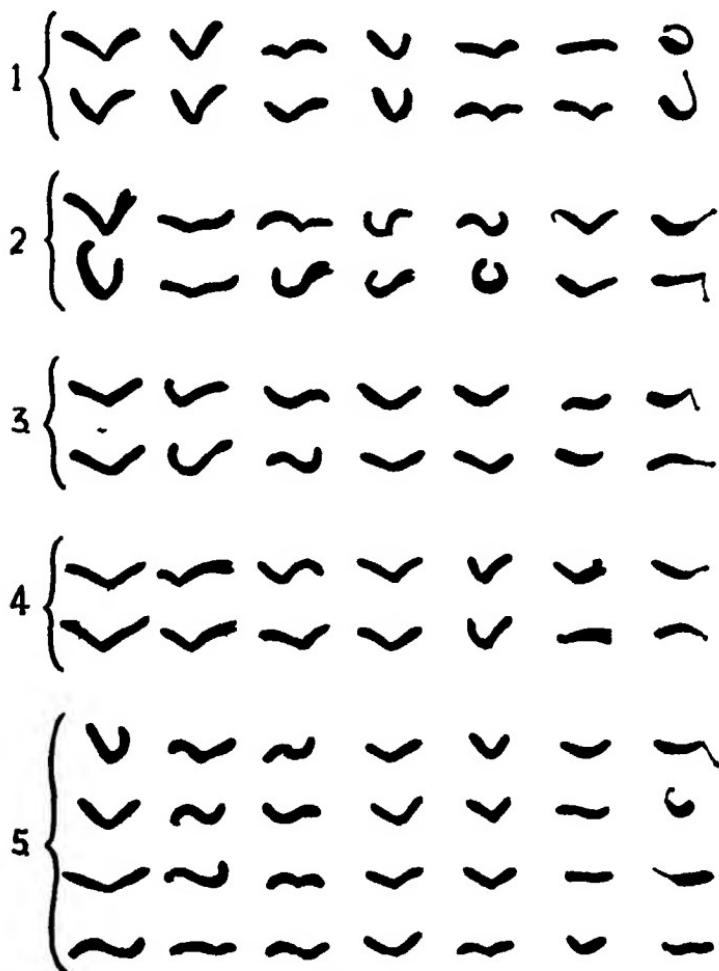


FIG B

1 *Rosa lutea* var. *punicea*
2 *R. gymnocarpa*
3 *R. pisocarpa*

4 *R. Soulieana*
5 *R. spinosissima*

chromosome of *R. spinosissima*, those in *R. lutea* var. *punicea* seem to offer a more or less constant deviation in configuration

As far as the other chromosomes are concerned, type I (first vertical column) appears to be distinctly longer than the remainder and to possess a median or almost median constriction. In type II, we have a chromosome a little shorter with a constriction perhaps best considered as submedian. The two following types, types III and IV, are practically subequal in size, a little smaller than type II and like it display submedian constriction. Type V, in general the smallest chromosome of the complement except those carrying satellites, reveals a median or almost median constriction. Lastly, type VI usually manifests itself as a more or less curved rod, *not* of the conventional shape generally attributed to the somatic chromosome of *Rosa*, but affording characteristics sufficiently strongly marked to single it out from the other types. In its case there are indications in *R. lutea* var. *punicea* and *R. gymnocarpa* that further work may lead to modification of our views as to its salient features.

In publishing this paper we wish to emphasize the fact that it is to be looked upon as essentially preliminary, and we intend, if necessary, when publishing our final work on the subject of chromosome morphology in *Rosa*, to revise the species just now discussed.

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THE INFRA-RED ABSORPTION OF FUSED AND CRYSTALLINE QUARTZ FROM 2μ TO 8μ

By F. E. McGINNETY, M.Sc.

The following is an attempt to unify the available data on the Absorption, in this region of the Infra-Red, of Fused Quartz and Crystalline Quartz. Several investigators have worked in this particular region, but since they have used different thicknesses of quartz their results are difficult to compare. In most cases the absorption values have not been corrected for reflection at the quartz surfaces.

In the present paper, the absorption values have been taken from Tables or curves in the published papers. The Reflection values used in the Reflection Correction co-efficient are those obtained by Reinkober.

In the case of Crystalline Quartz, the results considered are those obtained using plates cut perpendicular to the Optic Axis.

In the derivation of the Absolute Absorption Coefficient, some account must be taken of the reflection of light by the quartz plate. A correction co-efficient has been calculated and applied to the Transmission values.

The Reflection Correction Co-efficient was derived as follows —

Consider a ray AB incident normally on a slice of

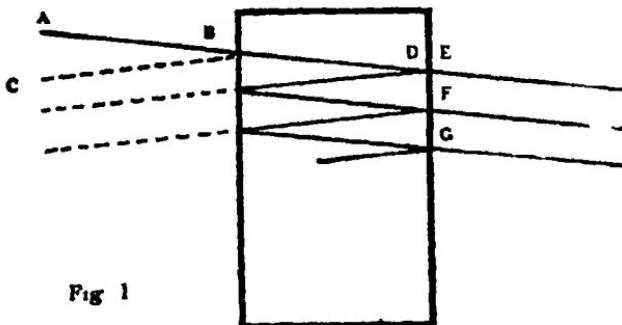


Fig. 1

quartz (In the diagram, Fig. 1, the ray is drawn at oblique incidence, so that the internal reflections can be shown.)

Part of the ray BC is reflected at the first quartz surface. When the incident ray is of unit intensity, and R is the fraction reflected, $1 - R$ is transmitted through the first surface. Passing through the quartz the ray suffers partial absorption, the magnitude of the absorption depending on the frequency of the radiation. T being the fraction transmitted for a given frequency, the intensity of the ray at D is $T(1 - R)$. A fraction of this, R, is reflected back into the quartz, and a fraction $1 - R$ is transmitted into the air. The intensity at E is therefore $T(1 - R)^2$. The portion that is reflected at D, after being again partially reflected at the opposite surface, finally reaches F, with an intensity of $R^2T^3(1 - R)^2$. Similarly the ray at G is of intensity $R^4T^5(1 - R)^2$.

The total intensity of the emergent ray is the infinite sum of such rays.

$$T_1 = T(1 - R)^2 + R^2T^3(1 - R)^2 + R^4T^5(1 - R)^2 + \text{etc.}$$

$$T_1 = \frac{T(1 - R)^2}{1 - R^2T^2} \quad (1)$$

T_1 is the intensity which is actually measured.

$$\text{From (1)} \quad T = \frac{- (1 - R)^2 + \sqrt{(1 - R)^4 + 4T_1^2 R^2}}{2T_1 R^2} \quad (2)$$

Expanding the expression under the root sign,

$$T = \frac{T_1}{(1 - R)^2} - \frac{4T_1^2 R^2}{(1 - R)^4} + \dots \text{higher terms.}$$

Since, in general, R is small, being of the order of .03, the second term may be neglected.

R becomes large for both Fused and Crystalline Quartz between $\nu 1280$ and $\nu 900$, this being a region of "metallic reflection." R is .89 at $\nu 1100$. Beyond $\nu 1250$ there are no accurate transmission values obtainable, so that only the region $\nu 4000$ and $\nu 1250$ is considered here. The correct transmission values for frequencies which have large reflection co-efficients have been calculated direct from the quadratic root (2).

Having obtained the true transmission values, the Absorption Co-efficient K is calculated from

$$T = e^{-kt}$$

where t is the thickness of the quartz in millimetres.

The Absorption Co-efficients are shown in Tables I and II. The curves of the Absorption Co-efficients of Fused Quartz and Crystalline Quartz are drawn on one sheet for direct comparison purposes. Fig. 2 shows the variation in K in the region ν 4000 to ν 2500, and Fig. 3 in the region ν 2500 to ν 1250. Lines are drawn across the curves to indicate the thickness of quartz necessary for 50% transmission for any given frequency. This should be a useful guide in the choice of the thickness of plates to be used in future work, as well as being an indication of the magnitude of the absorption at any given point.

In the graphs and in the discussion following, wave-numbers are used in preference to wave-lengths, as having more practical physical significance. The wave-numbers of fundamental bands are proportional to the characteristic frequencies of the molecule, and the calculated combination bands are derived from the wave-numbers of the fundamental bands.

Discussion of Results.

The region studied has been sub-divided into two regions. The first extends from ν 4000 to ν 2000, and the second from ν 2500 to ν 1250. This was found necessary since the absorption from ν 4000 to ν 2000 is very much less than in the remainder of the region. The greatest absorption in the first part is at ν 3700 in fused quartz, being '5, while in the second part the co-efficient at ν 1850 is nearly 15'0.

(a) ν 4000-2000.

Two curves are shown for crystalline quartz and two for fused quartz. Parlin's curve for fused quartz agrees fairly well with Dreisch's although Parlin finds small bands which are unresolved by Dreisch. Also, Parlin's curve

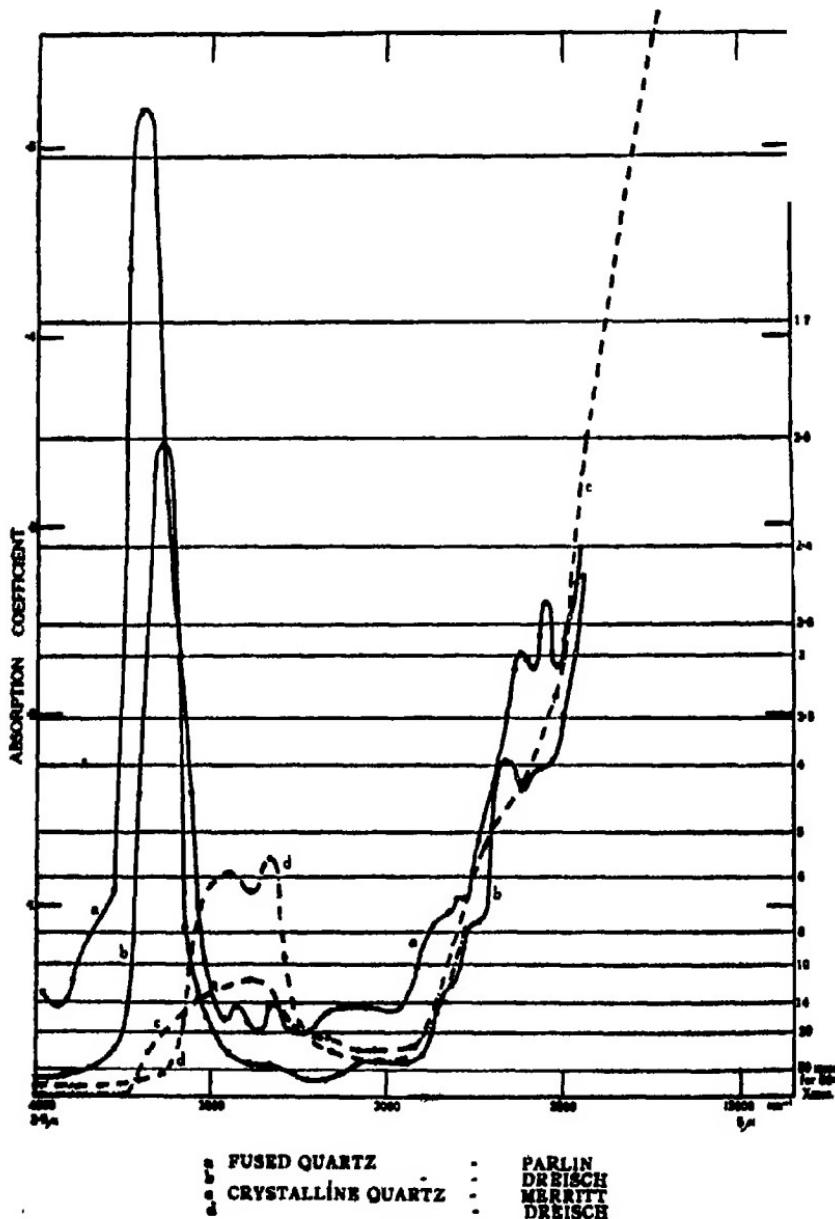


Fig. 2

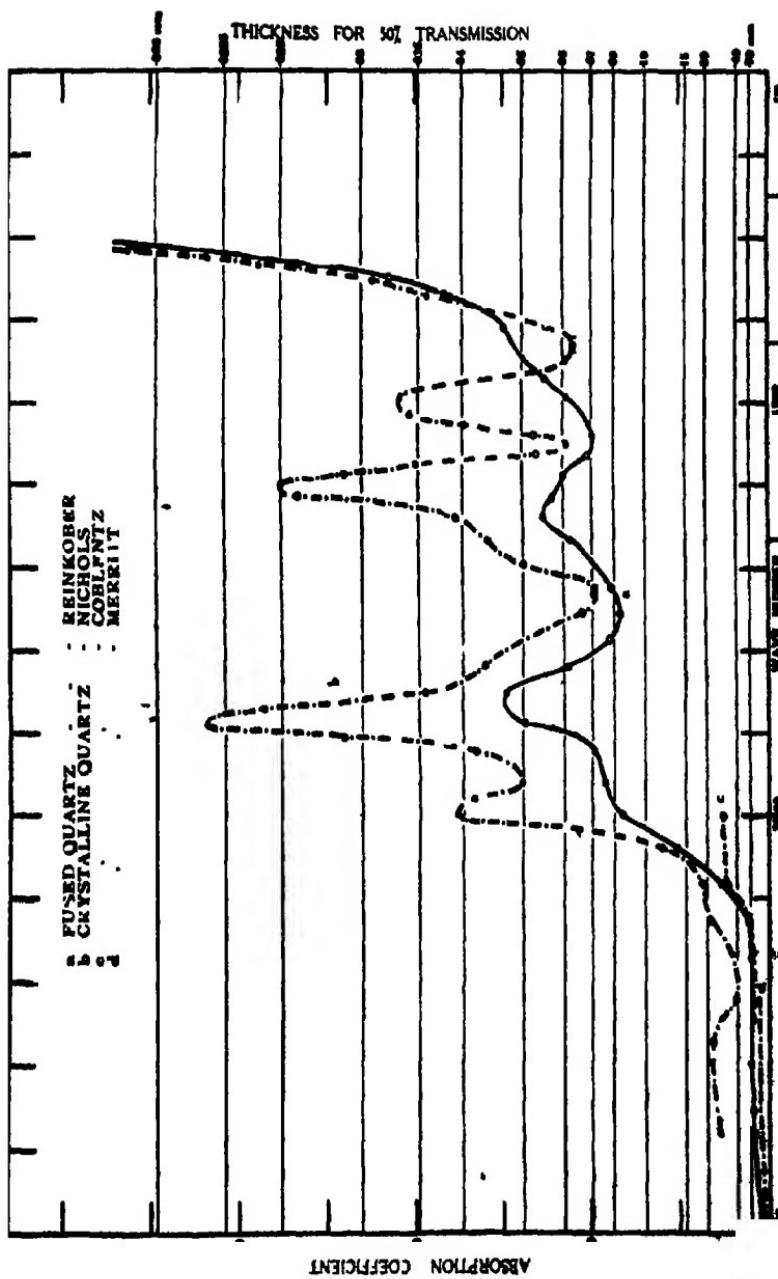


Fig. 3

shows stronger absorption near 3700 than that of Dreisch, and the positions of the bands in the two curves do not quite coincide, Parlin's value being 3690, and Dreisch's 3636

Parlin resolves two small bands at 3425 and 3324, which Dreisch does not show. Parlin makes special reference to these two bands, and to the fact that Dreisch found, in Crystalline Quartz, two bands at 3436 and 3330. While these bands may occur in both quartz forms, Parlin points out that a microscopic examination of his specimen of fused quartz with polarized light showed some slight structure. This is consistent with the view that fused quartz, being a super-cooled form reverts slowly, at low temperatures, to its natural crystal form. Parlin's apparatus was of a higher resolving power than Dreisch's, so that this may explain Dreisch's failure to observe these two bands in fused quartz. Also, the thickness of quartz used by Dreisch was two and a half times that used by Parlin, and his transmission values were correspondingly smaller.

Another difference between the two curves shows near the end of the region. Parlin finds two small bands on either side of 2600 at 2625 and 2554, while Dreisch shows one at 2667 and a possible weak one at 2550. These must seemingly be the same pair of bands but there is some discrepancy in their positions.

There are some indications of weak bands between 2700 and 3000 on both curves, but these are too indefinite to measure.

The main difference between the two curves for Crystalline Quartz is that Dreisch has resolved the band shown by Merritt at 3400 into two at 3436 and 3330. Dreisch's apparatus was an improvement on that of Merritt, his work being done thirty years later.

Comparing the curves for Crystalline and Fused Quartz, they seem to be very different at first sight. Examined closely, however, they are remarkably similar. The intense band in fused quartz at 3690 appears to be one great difference, but Plyler (*Phys. Rev.* 33, 48) found a very slight band in crystal quartz at this wave-number.

Merritt's curve for crystalline quartz does not show bands corresponding to those at 2625 and 2554 in fused quartz. It is possible that an instrument of higher resolving power would show corresponding bands in crystalline quartz.

Possibly in this region the same bands occur in both forms, but with very great differences in the relative intensities in the amorphous and crystalline form.

(b) 2500-1250.

In this region there are noticeable differences in the absorptions of fused and crystalline quartz. The main difference is that beyond 2100 crystalline quartz absorbs more strongly than fused quartz. The thickness of quartz used by Nichols and Reinkober were of the same order, 0.018 mm. for fused quartz and 0.07 for crystalline quartz. It might be noted that Nichols measured the thickness of this plate very accurately by an interference method. The plate used by Reinkober was not uniform in thickness, varying from 0.055 mm. to 0.106 mm. The value given is the average thickness. This uncertainty of the true thickness renders doubtful the accuracy of the absorption co-efficients for fused quartz in this region.

The first band in this region for crystalline quartz is given by Nichols at 2310 and by Coblenz at 2299. The band does not show well with the scale used, but is quite definite. Merritt's curve for crystalline quartz does not show this band, nor is a corresponding band to be found in Reinkober's curve for fused quartz.

Again, in crystalline quartz there are four bands, 1995, 1887, 1602 and 1504, and in fused quartz two at 1857 and 1640. It is probable that 1887 and 1602 in crystalline quartz correspond with 1857 and 1640 in fused quartz. The fused quartz curve suggests a weaker band near 1980 and another near 1440. These may correspond to the crystalline quartz bands at 1995 and 1504. Here again are discrepancies in wave-number, also there is a suggestion of a band in crystal quartz at 1675. It would appear that

a further survey of this region, especially in the case of fused quartz, would be fruitful.

In Table III are listed the absorption bands with their relative intensities, which are proportional to their absorption co-efficients.

My sincere thanks are due to Dr. W. E. Curtis for his valuable help and advice during the preparation of this paper

TABLE I.
CRYSTALLINE QUARTZ.
Dreisch. t = 9.0 mm.

Wave Number	Wavelength in μ	Corrected Transmission	K
4000	2.5	.9544	.00518
3703.7	2.7	.9273	.00839
3636.4	2.75	.8966	.01213
3571.4	2.8	.6745	.0437
3448.4	2.9	.3479	.1173
3389.8	2.95	.3804	.1074
3333.3	3.0	.3260	.1245
3289.4	3.04	.5214	.0724
3246.8	3.08	.7076	.0384
3164.6	3.16	.7597	.0305
3076.9	3.25	.8026	.0244
3030.3	3.33	.8021	.0245
2932.6	3.41	.7907	.0261
2857.1	3.5	.6656	.0452
2777.8	3.6	.4541	.0877

Table I.—continued.

Merrit $t = 3.91$ mm.

Wave Number	Wavelength in μ	Corrected Transmission	K
4000	2.5	9992	.00024
3745.3	2.67	9973	.00069
3676.5	2.72	9143	0230
3533.6	2.83	.8214	0503
3389.8	2.95	7879	.0610
3257.3	3.07	8690	0359
3154.6	3.17	9115	.0237
2958.6	3.38	9274	0193
2724.8	3.67	.5995	.1308
2617.8	3.82	.5235	.1655
2525.3	3.96	.4414	.2092
2427.2	4.12	2578	.3467
2222.2	4.50	.1068	.5720

Coblentz $t = 1.3$ mm.

Wave Number	Wavelength in μ	Corrected Transmission	K
2857.1	3.5	.8659	.1107
2500.0	4.0	.5608	.445
2352.9	4.25	.3109	.899
2298.9	4.35	.2676	1.014
2247.2	4.45	.3101	.901
2127.7	4.7	.2129	1.190
2083.3	4.8	.0531	2.258
2000.0	5.0	.0370	2.536

Table I.—continued.

Nichols t = .018 mm.

Wave Number	Wavelength in μ	Corrected Transmission	K
2381·0	4·2	.9516	2·756
2272·7	4·4	.9446	3·166
2222·2	4·5	.9669	1·869
2127·7	4·7	.9446	3·166
2083·3	4·8	.9350	3·733
2040·8	4·9	.8984	5·952
2000·0	5·0	.7281	17·630
1980·2	5·05	.7412	16·640
1960·8	5·1	.7783	13·920
1923·1	5·2	.7409	16·660
1904·8	5·25	.6488	24·030
1886·8	5·3	.5630	31·910
1851·9	5·4	.7048	19·430
1818·2	5·5	.7494	16·030
1754·4	5·7	.8285	10·450
1724·1	5·8	.8388	9·765
1694·9	5·9	.7801	13·800
1666·7	6·0	.7511	15·900
1639·3	6·1	.7270	17·710
1612·9	6·2	.6187	26·670
1600·0	6·25	.6079	27·650
1587·3	6·3	.6492	24·000
1574·8	6·35	.6978	19·990
1562·5	6·4	.7903	13·070
1550·4	6·45	.8160	11·300
1538·5	6·5	.7886	13·190
1526·7	6·55	.7346	17·140
1515·2	6·6	.6941	20·290
1492·5	6·7	.6875	20·820
1470·6	6·8	.7560	15·540
1449·3	6·9	.8151	11·360

Table I.—continued.

Nichols t = .018 mm.

Wave Number	Wavelength in μ	Corrected Transmission	K.
1428·6	7·0	·8214	10·91
1408·5	7·1	·7994	12·44
1388·9	7·2	·7575	15·43
1369·9	7·3	·7068	19·28
1351·4	7·4	·6683	22·39
1333·3	7·5	·5950	28·84
1315·8	7·6	·5212	36·20
1298·7	7·7	·3668	55·0
1282·1	7·8	·1919	91·7
1265·8	7·9	·1346	111·4
1250·0	8·0	·0719	146·2

TABLE II
FUSED QUARTZ. Parlin $t = 2.0$ mm.

Wave number	Wavelength in μ	Corrected Transmission	K.
3977.9	2.514	.8963	.0548
3935.5	2.541	.9081	.0477
3894.0	2.568	.8846	.0614
3775.0	2.649	.8046	.1094
3736.7	2.676	.4172	.437
3699.7	2.703	.3531	.521
3663.0	2.730	.3852	.477
3627.2	2.757	.5350	.313
3591.8	2.784	.6303	.231
3557.5	2.811	.7267	.160
3490.3	2.865	.8883	.0592
3457.7	2.892	.9206	.0414
3426.0	2.919	.9089	.0472
3394.5	2.946	.9227	.0402
3363.5	2.973	.9314	.0355
3333.3	3.0	.9100	.0471
3274.4	3.054	.9314	.0355
3217.7	3.108	.9314	.0355
3162.6	3.162	.9131	.0455
3058.1	3.270	.9096	.0473
2960.3	3.378	.9094	.0474
2913.8	3.432	.8730	.0679
2868.6	3.486	.8342	.0906
2824.9	3.540	.8229	.0975
2803.5	3.567	.8100	.104
2782.3	3.594	.8116	.1044
2741.3	3.648	.7633	.135
2701.3	3.702	.7207	.164
2662.4	3.756	.6711	.199
2643.4	3.783	.6385	.224
2624.7	3.810	.6280	.233
2606.2	3.837	.6319	.229
2588.0	3.864	.6380	.225
2570.0	3.891	.6164	.242
2552.4	3.918	.5951	.259
2534.9	3.945	.6265	.234
2517.6	3.972	.6369	.226
2500.0	4.0	.6195	.239
2483.3	4.027	.6044	.252
2466.7	4.054	.5830	.270
2450.4	4.081	.5614	.289

Table II.—continued.

Dreisch t = 5.03 mm.

Wave number	Wavelength in μ	Corrected Transmission	K
4000·0	2·5	.9507	.0100
3921·6	2·55	.9458	.0111
3846·2	2·6	.9265	.0152
3773·6	2·65	.8810	.0252
3703·7	2·7	.4512	.158
3636·4	2·75	.1779	.343
3571·4	2·8	.6386	.089
3508·8	2·85	.8096	.042
3448·3	2·9	.8912	.0229
3389·8	2·95	.9157	.0175
3333·3	3·0	.9171	.0172
3225·8	3·1	.9548	.0092
3174·6	3·15	.9564	.0091
3125·0	3·20	.9367	.0130
3076·9	3·25	.9136	.0180
3030·3	3·3	.9105	.0186
2941·2	3·4	.9118	.0183
2898·6	3·45	.8954	.0220
2857·1	3·5	.7928	.0461
2816·9	3·55	.7435	.0589
2777·8	3·6	.6518	.0851
2739·7	3·65	.6285	.0923
2702·7	3·7	.4902	.142
2666·7	3·75	.4119	.176
2631·6	3·8	.4327	.167
2614·4	3·825	.4455	.161
2597·4	3·85	.4324	.167
2564·1	3·9	.4207	.172
2531·6	3·95	.4122	.176
2500·0	4·0	.3666	.199
2469·1	4·05	.3100	.233
2439·0	4·1	.2534	.273

Table II —continued

Reinkober $t = 07$ mm

Wave number	Wavelength in μ	Corrected Transmission	K
2500 0	4 0	9610	573
2381 0	4 2	9540	763
2272 7	4 4	9345	968
2173 9	4 6	9339	977
2127 7	4 7	9241	1 127
2083 3	4 8	8289	2 680
2040 8	4 9	7037	5 020
2000 0	5 0	5628	8 21
1960 8	5 1	5246	9 22
1923 1	5 2	5021	9 84
1886 8	5 3	3797	13 78
1851 9	5 4	3530	14 87
1818 2	5 5	4513	11 30
1785 7	5 6	5335	8 98
1754 4	5 7	5588	8 31
1724 1	5 8	5385	8 84
1666 7	6 0	4579	11 16
1639 3	6 1	4117	12 64
1612 9	6 2	4252	12 22
1587 3	6 3	4459	11 54
1562 5	6 4	4921	10 13
1538 5	6 5	5013	9 86
1492 5	6 7	4514	11 36
1470 6	6 8	4141	12 59
1408 5	7 1	354	14 83
1369 9	7 3	283	18 03
1333 3	7 5	155	26 63
1298 7	7 7	0616	39 83
1282 1	7 8	0265	51 87
1219 5	8 2	0275	51 33

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POLLEN ANALYSIS OF THE PEAT ON
HEATHERY BURN MOOR,
NORTHUMBERLAND.

By

A. RAISTRICK, PH.D., M.SC., AND K. B. BLACKBURN, D.SC.

Heathery Burn Moor lies five miles south-west of Blanchland, and rises to about 1,700 feet O.D., the higher part being a gentle dip slope of Yoredale beds. This moor top was formerly a wet moss or bog, but about forty years ago was drained to facilitate peat-cutting and to improve the pasture. Since the draining, heather, with some cotton grass, has spread over the surface, and sphagnum moss is still found in the hollows and in the damper parts by the stream edges. Between 1,500 feet and 1,600 feet O.D. the peat is now exposed to a depth of 6 feet in a peat cutting, where, by the kindness of Mr. Marshall and Dr. Garrett, we were enabled to examine the peat and to collect material.

The sections exposed show clearly an upper layer from 8 inches to 12 inches brown, fairly friable peat, composed largely of sphagnum. Below this, up to 2 feet 6 inches of dark brown, much decomposed peat of cheesy consistency, resting on a basal layer of from 1 foot to 2 feet brown peat, full of roots and fragments of wood. The whole section rests on sandy, cream-coloured clay. From about 3 feet down in the section, small twigs and woody material are abundant. A small vertical column was taken from the clay at the base, to the sphagnum material at the top, and in subsequent examination, specimens were taken from the column at intervals of 2 inches. These samples, excluding the clay, are numbered from the bottom upwards, 1 to 16. In preparing the material for microscopic examination the following method, after much experiment, was found to give the most satisfactory results. About 1 cc. of the peat sample is digested in ammonia (approximate strength 1/10 of .880 solution) in a water-bath

for about six hours, a boiling-tube providing a handy-sized container. The solution of humic substances and the residues are poured into a larger vessel, filled up with water, and, after a few seconds, decanted, to free from sand grains. The decanted material is washed in several waters, it being necessary to allow considerable time for settling between each washing. The peat residue is a fine black mud which includes any pollen present in the original peat. A spot of this mud on a slide is cleared with lactophenol, and mounted in safranin glycerine jelly. In the slides so prepared the tree pollen is easily examined under the microscope, as the grains take the stain very well indeed, and detail of structure and surface marking can easily be determined. The total number of each kind of tree pollen present is counted, using for convenience a mechanical stage. The principal kinds of pollen found in the peats are *Betula*, *Pinus*, *Alnus*, *Quercus*, *Tilia*, *Ulmus*, *Corylus*, and much more rarely *Fagus* and *Carpinus*. With the tree pollen, pollen of Ericoid plants and spores of Sphagnum and ferns are often very numerous.

In the micro study of peat it has been found useful to select a number of forest tree pollens, and in any given sample to express the number of each species or group as a percentage of the total number present. For this purpose it is usual to express, as a percentage of the total tree pollen, the number of *Pinus*, *Betula* and *Alnus* separately, and of the two groups, *Quercus*, *Tilia*, *Ulmus*, and *Fagus*, *Carpinus*. Hazel is calculated as a percentage of this total, in which, however, it is not included. For comparative use, these percentages from serial samples from a single locality can be plotted as a graph, or for an individual sample, or average of several, can be shown as as a "pollen spectrum." This latter is made by dividing the circumference of a circle in the proportion of the various pollen percentages, and filling in the sectors of these proportions with hatchings or symbols to represent the genus. It is a generally accepted custom to start from the "south" point of the circle and plot the pollen in the order just named. The spectra give the constitution of

several pollen analyses at a glance.

As a preliminary testing of technique, and to establish a local scale of reference, it was decided, in the wider study of Northumberland peats now in progress, to construct both graphs and spectra for the Heatherly Burn peat in more detail than is generally necessary, and to check the results by repeating the counts on a large amount of material and also on material prepared in different ways. In the work now recorded, material was prepared from 16 horizons in the peat, and in 12 cases tree pollen were counted and determined until not less than 300 pollen grains had been counted for each sample. In other cases tree pollen was more scarce and only about 100, and in some cases only 20 to 40 grains could be found. *Sphagnum* spores and Ericoid and Hazel pollen were counted separately, and do not enter into the percentages. Fig. 1 gives the results of these counts in graph form. Specimens 1 to 13 show abundant tree pollen with little *Sphagnum* or ericoids in the first ten, but at 11 these come in to about twice the total quantity of tree pollen, ericoids dominating. At 14 tree pollen begins to fail and *Sphagnum* dominates everything.

The tree assemblage in the neighbourhood, which is reflected in the pollen counts, shows interesting changes and comparisons with the present flora. Throughout the peat which contains tree pollen, that of *Pinus* is present but varies only slightly between 2 per cent. and 6 per cent.; *Betula* varies between 30 per cent. and 56 per cent., and *Alnus* between 28 per cent. and 51 per cent., and the "mixed oak wood" (*Quercus* + *Tilia* + *Ulmus*) between 4 per cent. and 16 per cent.; *Fagus* is rare up to 3 per cent., and *Carpinus* occurs only at one level, 8. Hazel is present all through, and is very variable; expressed as a percentage of the total tree pollen, it varies between 8 per cent. and 30 per cent. It is rather surprising that no *Salix* was found, but careful search failed to identify any of its pollen.

From the graph of percentages it may be seen that at the base of the peat, Alder and Birch, taken together, form 93 per cent. of the total tree pollen, and are almost

equal (47 per cent and 46 per cent) From samples 2 to 5 it will be seen that Birch rises to its maximum, then decreases to a fairly steady figure, Alder taking its place

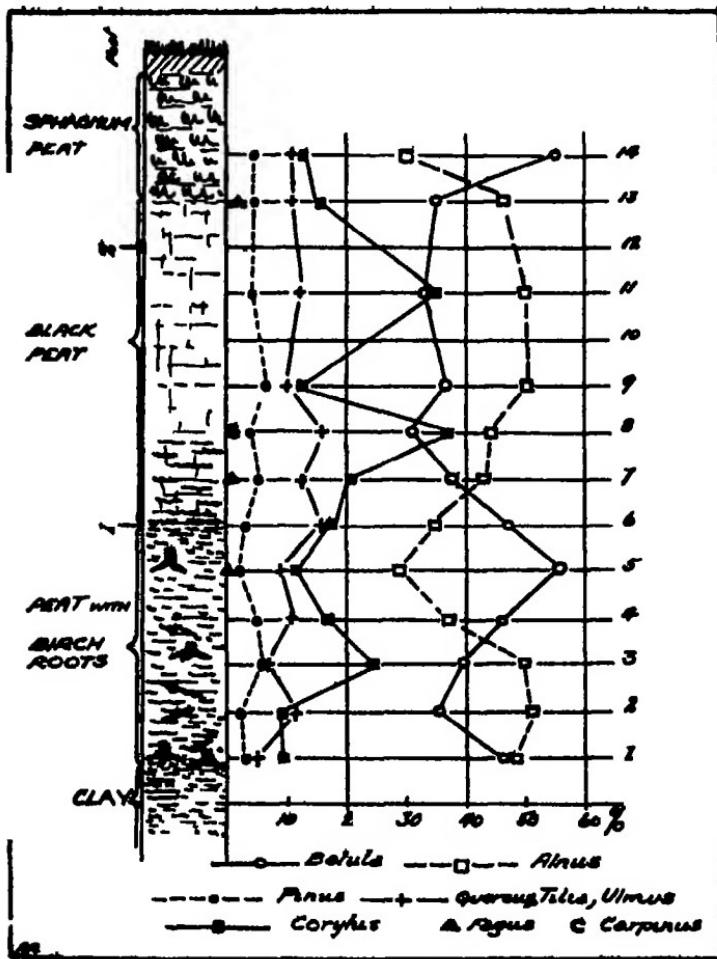


Fig 1

as the dominant pollen in samples 6 to 13 In sample 14 tree pollen was becoming rare, Birch being by far the commonest pollen found, and continuing in samples 15 and 16 as the only tree pollen In this upper part the

spores of *Sphagnum* and the ericoid pollen were extremely abundant, many hundreds being counted in a single preparation. Pine is present all through in small quantity and shows little variation. The mixed oak wood (Q,T,U) is commonest in the middle of the section, then fairly steady up to the *Sphagnum* layer. For comparative purposes, average spectra of different parts of the peat are used, and on the method used in other peat analyses, here and abroad,^{2 4 5 6 9} the crossing of the descending Birch and ascending Alder curve (between 6 and 7) is taken as marking one division, and the reverse crossing, at the dying out of tree pollen (between 13 and 14), the next. Other points of division are taken above and below these, if the peat is of sufficient age to include more (fig. 2). In the Chat Moss, Lancs., peats, these two crossings are

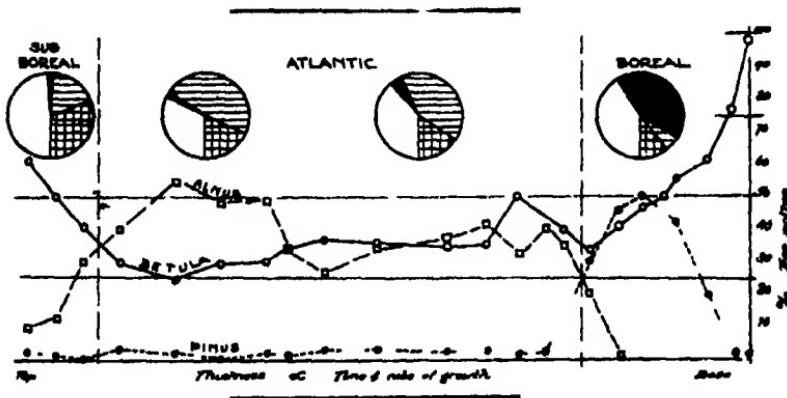


Fig. 2.

closely paralleled, and the curves have close similarity in their variation; the point where the Blanchland curve starts, with Birch-Alder just crossed, corresponds with the division (in the Chat Moss peat) between the Boreal and lower Atlantic phase of peat formation.^{4 5 13} Before this point in Chat Moss, Pine is decreasing from its maximum (about 50 per cent.), and Alder has just appeared and rising to its first dominance. The Blanchland curve on the whole is very similar to the "Atlantic" portion of

the Chat Moss curve, and to that of several other peats determined as of Atlantic age.^{3 4 5 6 13} The spectra show this similarity with great clearness. Spectra have been similarly prepared of the Chat Moss peats, of Kildale Moss, Cleveland, and of Marsden Hill, Yorks., W.R., in each case averaging the curves for the different divisions recognized. These are given in Fig. 3. In the Blanchland peat the lower part (1-6) is the peat with roots and stumps of trees, the upper part, the rest of the peat nearly

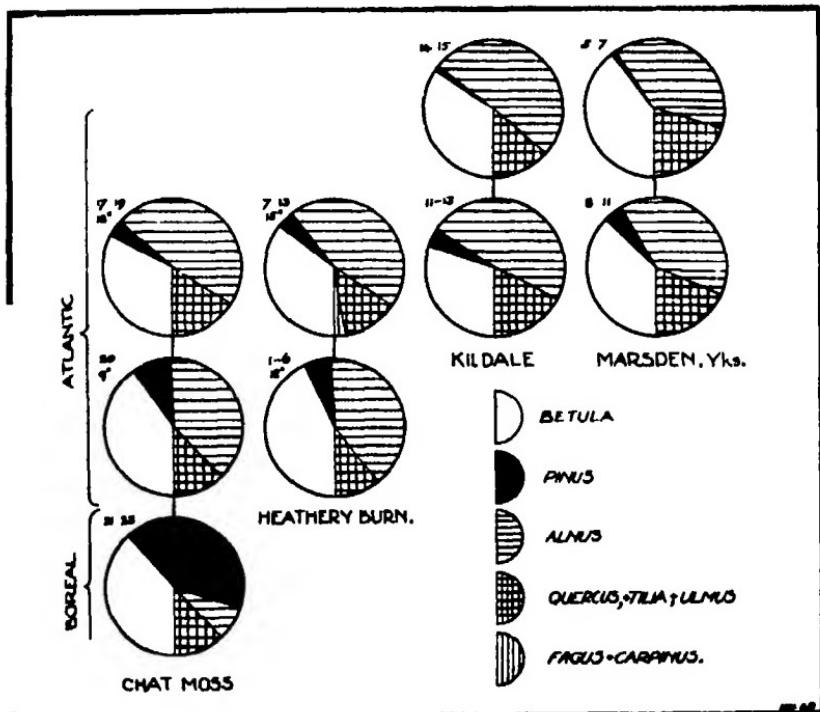


Fig. 3.

to the dying out of pollen. The correlation of the tree succession with the climatic periods of Blytt and Sernander¹¹ has been carried out for Chat Moss by Erdtman^{4 5} and for Kildale and Marsden by Erdtman and Woodhead.^{3 13} Accepting these correlations and reserving their discussion until more work has been done, it is clear

that the Blanchland peat includes practically all Blytt and Sernander's Atlantic period (warm, moist, and oceanic conditions), and the base of their sub-Boreal (warm and dry) with Birch becoming dominant and Alder disappearing. It must be remembered that the tree pollen reflects the conditions in the surrounding areas, not those of accumulation of the peat itself, and it is assumed in this work that the changing tree flora was largely a response to changing climatic conditions.

These studies of peat show the former far greater extent of forest trees in the Pennine area, tree remains and tree pollen being found in peats up to 2,300 feet (O.D.) both in this area and in many observed by Mr. Lewis around the Cross Fell-Mickle Fell massif.¹ The remains of Birch occur in the peat at far greater heights than it grows now, the tree limit in this area at present being about 1,000 feet O.D. in the sheltered valley bottoms. Lewis has given a general succession in the peat on the higher parts of Cross Fell:² first an Arctic or sub-Arctic plant bed with *Salix arbuscula*, *Salix reticulata*, *Empetrum nigrum*, etc., resting directly on boulder clay; this sub-Arctic plant bed is frequently covered by *Phragmites communis* peat, and this in turn by the thick peat typical of the Pennine fells. At the base of the thick peat, almost wherever seen, is an horizon marked by stools and twigs of Birch (*Betula alba*) along with Alder (*Alnus glutinosa*), etc.; this is Lewis's forest layer, defined by the presence of actual plant remains. The examination of the pollen has extended the tree assemblage of this lower forest layer, which is the base of our lower Atlantic peat. The forest peat passes upward into *Eriophorum*, *Sphagnum* and *Calluna* peat. He has no record of Pine in the peat of these higher slopes, and the pollen shows only a comparatively small amount, when one considers the large air sacs typical of pine pollen, which make it one of the easiest of pollens to be carried by the wind, and ensures its presence in peats or pond muds, if any pine at all is in the neighbourhood. The peats, taken over a larger area, indicate a definite succession in the tree flora of north-west Europe, Birch

and Pine being the earliest trees in post-glacial time, Alder comes next, followed soon by the mixed oak wood, while the latest to arrive are Beech and Hornbeam. It has been stated that Hornbeam has not yet been found in British peats, but there is no doubt about the pollen in the Blanchland peat, this statement leading to especially careful checking.

Other peats have been examined on many parts of the Pennines, and in Northumberland, and will form the basis of further work, and wider correlations, when pollen analyses are completed.

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1930.

- Nov. 5th—"Descartes Re-visited." By Prof. A. Robinson.
.. 13th—"The Identity and Geological Horizon of the Coal Seam exposed in the early Autumn of 1930 on the foreshore at Seaton Sluice, Northumberland." By Dr W. Hopkins.
.. 27th—"Lupin Alkaloids." By Prof. G. R. Clemo.
Dec. 5th—"The Nature of Intelligence" By Prof. Godfrey H. Thomson.
.. 16th—"Determination of Atomic Weights by an Optical Method." By Dr A. Elliott.
.. 18th—"On the Cytology of Hybrid Roses belonging to the section *Canina*, with some remarks on *R. juddsii*, a new British species" By Prof. J. H. Harrison and Dr. K. B. Blackburn
.. 18th—"Some Preliminary Notes on the Cytology of the Genus *Scrophularia*." By Mr. I. T. Pollard

1931.

- Jan. 22nd—"Electrical Perception by Deep Sea Fish." By Prof. W. M. Thornton.
.. 28th—"A Tidal Problem." By Prof. G. R. Goldsborough.
Feb. 25th—"Luminous Discharge Through Gases" By Prof. R. Whiddington.
Mar. 5th—"A Method of Preventing the Oxidation of Steel at High Temperatures." By Mr. C. E. Pearson.
.. 5th—"The Effect of Manuring on the Feeding Value of Pastures." By Dr. A. A. Hall.
.. 12th—"The Infra Red Absorption of Fused and Crystalline Quarts from 2w to 8w" By Prof. W. E. Curtis and Mr. F. E. McGinnety.
.. 12th—"New Bands in the Spectrum of S₄." By Prof. W. E. Curtis and Mr. S. Tolansky
.. 16th—"The Fertility of *Rosa spinosissima* and certain of its hybrids." By Prof. J. W. H. Harrison.
.. 16th—"The Morphology of the Somatic Chromosomes in *Rosa*." By Prof. J. W. H. Harrison and Dr. K. B. Blackburn
.. 16th—"Contributions to the Cytology of Some Members of the *Orchidaceae*." By Miss M. M. Richardson.
.. 16th—"Notes on the Chromosomes of Angiosperms, including some new numbers" By Dr K. B. Blackburn.
.. 16th—"A Preliminary Investigation of a Durham Peat by means of Pollen Analysis." By Dr. A. Raistrick and Dr. K. B. Blackburn.
May 6th—"Some Experiments in Nitration." By Prof. J. I. O. Masson.
June 2nd—"Folding by Decollment in the Pennines." By Prof. H. G. A. Hickling.
.. 2nd—"The Permian Yellow Sands of N.E. England." By Dr. M. B. Hodge
.. 2nd—"Tertiary Volcanic Rocks of N.E. Ireland." By Mr. S. Tomkiesoff.
.. 2nd—"Xenolithic Inclusions of the Acklington Dyke." By Mr. G. Mockler

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- ABELL, W. S. "Direct Flooding Calculations" *North East Coast Institution*, 1930, March.
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- "On the effect of the shape of the cathode on the glow discharge. The 'Heteronormal' current density effect."—William Stephenson, 1929.

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The Alexander Pedler Lecture, 1931.

"PROBLEMS IN THE NATIONAL TEACHING OF SCIENCE"

By Professor IRVINE MASSON, M.B.E. D.Sc. F.I.C.

Delivered on the 21st October 1931 in Armstrong College,
Newcastle upon Tyne

Sir Alexander Pedler, in honour of whose memory the British Science Guild founded the annual lectures of which this is the third, was a chemist, a meteorologist, and an educationist, and he was one of those public-spirited men who have given their labours to the civilizing of India. The first Pedler Lecture dealt with a wide climatic theme, and so it was a token of one major activity in which Pedler had to engage. The second, last year, was given by one who had been a colleague of his in India, in another field of science, botany, and it dealt with "Science Discipline." It would be tempting in this third lecture for me, as a chemist, to choose a chemical theme, but in fact that specialized side of Pedler's interests is independently commemorated by a separately endowed lecture, given each year in London. It may therefore be fitting and in accordance both with Pedler's own career and with the aims of the British Science Guild, if I deal with an educational theme. I shall therefore put before you some facts and views of the teaching of science in this country at the present day in our universities and schools.

The time is happily past when it was necessary to argue the principle that science must be an essential part (to varying extents) of everyone's education, everyone now admits that, but what remains is to put that principle properly into practice. School headmasters look upon their laboratory buildings as objects of official pride (though sometimes, still, perhaps, of private anxiety); they have followed—some eagerly, some reluctantly—the lead given to them and their public by the universities. So

strongly indeed has science teaching been fostered during the past thirty or forty years that it has created a situation —or perhaps better a movement which seems to many people to require investigation. Has the pendulum over swung? In displacing some of the excessive classical specialization which for so long made our general education lop sided have we indulged instead in excessive specialization in science? If we seek to answer this pen question we shall have first to put it in a much less vague form. It goes without saying that there are many intellects so keen and so concentrated in their focus that for them there must be highly specialized training if they are to develop their powers for their best service to mankind. For these people the question becomes therefore at how early an age they should be allowed to concentrate. Now if these people are so made as to follow a science as a lifelong career we should certainly make their preliminary training at school subservient to this purpose but not before they have shown their special aptitude quite unmistakably. In the course of what I have to say I shall suggest that our present school system leads to too many mistakes in the diagnosis of special scientific aptitudes that even when this is not the case the study of science at school is made intensive at too early a stage and that this prematurely intensive study not only displaces other non scientific school subjects which valuably subserve a scientific career but is also directly harmful in the later study of the particular science itself.

These statements (which I shall amplify) refer to the persons who ultimately can and should pursue a science intensively as a career. But we should be taking far too narrow a view if we regulated all our ideas by these people's needs. Their interests above all must be cared for for from them alone will come the advancement of learning. But the majority of students will eventually deal, not with things but chiefly with persons. They will utilize science not practise it, they will purvey it as school teachers apply it as physicians and surgeons as engineers, as practical men of different sorts or they will simply be alive to what it is and what it can do in human affairs.

And their management of their own kind of human doings will be clarified by a scientific outlook. What I am going to suggest is that in catering for these groups of persons, we need to inquire whether we at the universities do not drag them at the chariot wheel of the specialists, and, by so doing both mingle them and retard the chariots.

Criticism of this type is apt to be vague and I shall therefore try to be definite and at the same time to point out directions in which we may seek remedies for such defects as we discover. With this introductory survey, let us proceed. And first of all let us have before us the latitude and longitude of the territory in which we explore.

At the Public Schools of this country there are I think, some 60,000 boys of girls about the same number attend girls' Public Schools and (in round numbers) 400,000 boys and girls equally divided are pupils at the Secondary Schools managed by Local Education Authorities under the Board of Education for England and Wales.

There are therefore in the aggregate well over half a million boys and girls from among whom the universities of England and Wales will draw their students. And at these universities the total population of undergraduates is (in round numbers) 3,000 and 11 Scots universities another 11,000.

From the schools there flow to the universities of England and Wales each year approximately 10,000 new students. Taking 1928-9 as typical the new undergraduate entry was about 9,800 of whom 37 per cent came from Secondary Schools where they had constituted one-nineteenth (5.3 per cent) of the school leavers in that year. The corresponding figures for Public Schools are, I learn, not compiled. But indirectly I estimate that approximately one out of every three or four Public School leavers comes up to a university. This difference between the two types of school is partly due to differences in average ages of leaving for nearly three-quarters of Secondary School pupils (girls and boys) leave before they are seventeen, whereas Public School boys stay on longer. If then, we confine our attention to pupils leaving school at and after seventeen, we find much less difference in the proportions.

coming on to universities roughly one in three or four from Public Schools and (more exactly) one in six from Secondary Schools

Let us follow these pupils on to the universities and see what they do there. The full time undergraduate population of the whole United Kingdom we find is divided approximately thus. Out of fifteen or sixteen who begin a full degree course thirteen appear at the other end with a first degree. Of those thirteen seven follow Arts courses and other non scientific subjects four are students of medicine engineering or some other forms of applied science and two are students of pure science. Taking them all round there are about two and a half times as many men as women among them.

In all faculties together very nearly 9 000 first degrees are bestowed in the kingdom every year just now. And the remarkable fact is that when we come to ask how these 9 000 are divided between Honours graduates and Pass degree graduates we find that there are far more Honours than Pass. Only in the Scots universities is this not the case in Scotland for the past seven years the output of Pass graduates has been about three times that of the Honours.

In the universities of England and Wales (which I shall chiefly consider) the preponderance of Honours over Pass graduates is very marked. It has climbed steadily and rapidly since 1924 and earlier until in June 1930 we produced just two Honours graduates for every one Pass graduate. There were in fact 4 346 Honours graduates 2,216 Pass a difference of 2 000 and a ratio of 1.6. The actual numbers of the Pass graduates have changed little in the past three years but the curve slopes definitely downward for the last seven years thus in 1924 there were 3 114 Pass graduates 1926 2 776 1928 2 309 1930 2,216. On the other hand each June for the past five

¹ A large number of Secondary Schools do not particularly aim at producing university students and it seems probable therefore that from those which do the ratio of university entrants to school leavers over sixteen years of age is considerably greater than one to six.

years has seen a larger Honours output than the June before. The *total* graduations have changed very little (fluctuating about 6,500), so that what has been happening is that the Honours numbers have been growing at the expense of the Pass.² And I may mention that these facts remain substantially true when we except Oxford and Cambridge.

This is, I think, a rather important question in university policy. What is the growing preponderance of Honours due to? Probably there are several reasons. For one thing, some of the smaller universities may have been strengthening their staffs and curricula, and so have provided opportunities for Honours courses where none existed before but were badly wanted. In so far as this was the case, it is a matter for congratulation, a university without Honours courses would not be a university. But I do not think so many fresh Honours courses have been instituted as to explain the change. Again, it might be held that the universities were changing the principles upon which they select their students from the schools were declining applications from Pass candidates in order deliberately to make room for intending Honours ones. Or, if may be claimed, the schools are teaching better than they used. Again, perhaps the universities have lowered their Honours standards. However these things may be—and I shall touch on them later—unquestionably one of the chief factors is the preferential treatment now given by the Board of Education to graduates in Honours, when school-teaching posts are in question. The "Burnham Scale" for Board of Education school teachers, laid down in 1921 and again in 1927, gives lifelong advantages both in salary and in occupation to graduate teachers who have what is officially termed "A good Honours degree." The specification of what constitutes "good" Honours varies from one Local Education Authority to another; some put it at First Class, some at an upper division of the Second Class, some at Second Class Honours, none, as far as I know, extends the definition to lower classes.

² See Tables I, II, III

Now we have in our universities not only a large number of students who will later on decide to become school teachers, but also somewhere between 5,000 and 6,000 students who have already definitely promised to do so. Having been given four-year grants from the Board of Education for the purpose, they are pledged to undergo pedagogic training as soon as they complete their university studies proper, and then to enter the school-teaching profession. It is obvious that even if the universities did not specially persuade these young men and women into Honours courses the Burnham Scale would. Moreover, if a student, a would-be teacher, shows himself to be able, but not well cut-out for an Honours course which he has begun, it is exceedingly hard for his advisors at the university to move him over into a Pass course, the student resists the change, in view of all that it would mean to his future career, and too often the university authority's heart gets the better of his head, with the result that the student continues an Honours course from which he only gets less and less real good as he goes on. He may hack his way into an Honours degree, but he spoils himself by it.

The apportionment of degree-students between Pass and Honours seems to me so important and to be so pressing a question, that I must dwell upon it. In the first place, what is, or what ought to be, the difference between a Pass course and an Honours course? Let me refer you to an interim report issued early this year at Cambridge, by the syndicate which was charged by the University to consider their curricula for the ordinary B.A. degree (I quote from *The Times* of 24th April, 1931) "Any degree course," the Syndicate observes, "has one of two primary objects, either to train the candidates to think, or to impart useful information." The report goes on to say that the particular Pass courses with which it deals are based too exclusively upon the former idea; they indulge, it says, in a too intensive study of special subjects. And the report goes on to suggest "that a large part of the [Pass] course should have in view the other object—namely, that the candidates shall acquire a body of

information which will fit them to take an intelligent interest in life

I have quoted these words because they apply I believe to a very large proportion of our universities. When the Cambridge Syndicate speaks of taking an intelligent interest in life it does not we may be sure have in mind merely persons who will require in after life to take up no particular occupation on the contrary if my interpretation of the report is right the Syndicate is anxious that their ordinary or poll courses should form a really valuable equipment for the hard working citizen of to day and to morrow for the man who though he will never pursue original inquiry into these academic subjects for their own sake will utilize what he has learnt of them and from them in doing active work in the world Accordingly what the Syndicate says of its own University's ideals will surely be shared by any other

Note then the bold statement of the two primary aims —either to train the candidates to think or to impart useful information It is especially refreshing to have these presented as alternatives The Syndicate by inserting the word primary before aims implies I take it that the alternatives need not be mutually quite exclusive But they do represent two rival theories of university education which in some places come directly into conflict A middle theory which attempts to combine them both is naturally the true ideal but as a basis of universal practice it breaks down on two obstacles On the one hand teachers who can both instruct usefully and at the same time stimulate thought are rare We have in this country not far from a quarter of a million school teachers and we have some 3000 university teachers will it be claimed that each and every one of these is so trained and so gifted as to be capable of both functions? No teacher can create brains but one poor teacher spoils many and in education both good effects and bad are cumulative from one generation to the next The other obstacle to a nation wide fusion of the two sorts of teaching is obviously the student Not of course all of them, but the majority I have heard it said that most people

are nice but stupid—but that was a cynic and a teacher, as a member of the public I should prefer to say stupid but nice We may believe however that among the select body of young people who are chosen for the universities the stupid persons our Old Men of the Sea, are in the minority but so also are the brilliant ones Among the greater part the order of ability is quite high provided it is not misdirected And I must freely confess that I think we do misdirect far too many Does anyone who really knows our university students in different parts of the country honestly consider that as many as two-thirds of them or any majority have the peculiar aptitudes that are needed for specialized Honours courses? Yet these are the proportions that engage in Honours Surely it is best to admit what the Burnham Scale seemed to imply namely that our Pass courses have not been doing their duty We have used them too much as academic spoil heaps on which to cast the material thrown up in our digging for the special ability which is our peculiar quest and it is time that we set them in order I think we have acted as if the difference between Honours courses and Pass courses is that the able students are for Honours the stupid for Pass

The Pass courses should be the resort of people of ability who do not intend to devote their lives to the subjects of their academic studies In saying this I am not pleading for potted courses of this and that, scissors and paste stuff smooth and easy skimmings those of you who have read Dr Abraham Flexner's account of the pitiful methods of some American universities will need no other awful warnings to be put before you On the contrary to present to a class during two or three years the basic essentials of a science to exhibit its scope and its trend and its relationships to other fields of learning and to human work in general these are the tasks of a true Pass-degree teacher and to carry them out properly demands thorough learning special skill experience, and patience from the teacher, and real exertion from his students Neither those to whom such teaching is entrusted, nor those who receive it should have any

reason for feeling themselves less important to the university than the Honours specialists Their function is different their interests are different and their careers will be different

I further I do not see why well organized Pass courses should not provide fully for that difficult and almost unworkable ideal the General Honours degree in several special subjects at once As this stands at present, in the Faculty of Science it is one all consuming grind for the student who let it be remembered has long hours of laboratory work when his brother in Greats can be reading for himself—and it either breaks a good Pass student or spoils a good specialist There is nothing whatever to prevent suitable marks of distinction being granted to outstanding candidates for the Pass degree And if the Board of Education would admit Pass men of distinction to the status as teachers which they now allow only to Honours specialists I feel sure that the universities of the kingdom would welcome it and would be encouraged to take a measure of interest in their own Pass degrees which at present they are hardly free to give Whether this is actually being considered officially I do not know but it would seem to be a very fit subject for discussion and action between the conference of university principals and the Board of Education

I cannot leave the matter of Pass degrees without referring to one other aspect of it If you agree with me in regarding these courses as education for able people who are going to do something else then I hope you will follow me a step further For under such conditions it seems to me essential to make Pass degree courses in the Faculty of Science actually what, too often they only pretend to be at present and that is broad I do not mean too broad within each science dealt with a superficial treatment is of no use—but compulsorily broad in the choice of subjects, in the following way It should be made impossible for a man to be given a Pass B Sc if he has not studied, at the university itself, both biological and physical sciences If I dared, I would also add logic, both deductive and inductive, but that, I

suppose may be unworkable. But at all events, it should be necessary that, whatever groups of subjects a Pass student chooses, he must include not less than one year's study of biological science and one year's study of physical science. Too many at present go out from the universities with no knowledge of any biology whatever. Are we not all biological specimens?

What it is that really decides the new student's choice of subjects is familiar to everyone who has to advise them when they enter. It is extraordinarily hard to induce them to turn to any subject which they have not taken at school. If one suggests to a freshman that he might consider (for instance) geology as a valuable and interesting ingredient of his training, one usually sees a look of blank dismay, or (more daunting still) of polite dumb refusal, at the idea of tackling anything new at the advanced age of seventeen or eighteen. The student has to be told in such cases, that a university is a place where new worlds of thought and knowledge are made accessible to him and that he must not consider that all his life is settled by the limitations imposed upon him at school.¹

It is far too common, then, that a student's university curriculum is merely a prolongation of his school curriculum. I should like to see boys and girls persuaded quite forcibly by their school teachers to conceive of their passage to a university as an intellectual adventure, not as a mechanical "Safety First" proceeding. It is very natural, in these times of hard livelihood, that youths should be anxious for the degree-label which they hope will do so much for them, but I do earnestly invite school-masters to do their level best to make the university candidate postpone that anxiety, and come up prepared to let his mind enjoy itself for three or four years more. He will benefit, the universities will benefit, and the nation will benefit.

¹Cf. Tables V and VI with Tables II and III

Now I come to our Honours degrees. When we say that the first object of in Honours course is to make the student think, we use a rather loose phrase, let us stiffen it. The Honours student, I take it, must not only be taught what people know, in this science or that, he must be shown how they come to know it. Thus he must learn, to a greater or less extent, how he can unearth knowledge for himself. If this purpose does not permeate the whole of his curriculum, then it has surely no title to be called an Honours course in a science.

You may remember what a famous mountaineer once said about the history of an Alpine summit. At first, he said, it is an inaccessible peak, then it is a stiff climb; then an easy dry for a lady, and lastly, a run up on the funicular railway. It is like that with scientific discoveries. Those students of mountains who are not content with maps or with snapshots in the newspapers, but who make the journey to Switzerland, ascend the valleys, and are taken up to the summits in the funicular railway, are the Pass degree men. They see a great deal on the way up, and as they watch the precipices and snow-slopes past which the car takes them, they can understand something of the tasks which confronted their forerunners. They have won a splendid landscape and a new point of view, and have learnt more about the framework of the world than they had ever guessed at, and when they return home and walk upon the Sussex Downs, or look at man-made skyscrapers as they go about their business, they retain throughout life a scale and standards of comparison. But, though they have walked much and have seen more, they do not claim to have become climbers. This they must leave to the others who have trained themselves by long practice, who have been shown when to rope, how to cut steps up an ice-slope, and whether a rock face can be traversed or whether it must be passed by a descent and a fresh start up a new ridge. These, in their early stages, when they are being trained to use their hands and feet and heads on the mountain, are the Honours men. The process ought to produce intellectual fitness in all, and to lead many to a continued career of research.

That represents, broadly, the difference between Pass and Honours courses in science, as I see it, now let us examine the Honours work from a more definite point of view

In the older branches of learning, such as Latin and Greek literature, Greek philosophy, ordinary mathematics, and in the more elementary parts of language-learning, the corpus of material is fairly defined, and has changed very little during many generations. The problem of selecting a syllabus in such subjects remains now pretty much what it was when our grandfathers studied them. Imagine Porson, Bentley and Erasmus to be re-incarnated to-day from their several centuries, as candidates in the examination hall of the Classical Tripos, would not the hearts of the examiners leap within them at the learning laid before them? Such changes as have occurred in these studies have probably been in the direction of reducing the content, of reading fewer authors, or smaller parts of their writings than before. Only archaeology has brought developments which latterly have invaded the time formerly given wholly to 'authors,' and have helped to place them in a historical setting. At all events the point is that the primary body of material lies in manuscripts which have been available to the learned world at any time these four hundred years, *plus*, of course, human nature—which has been available even longer.

In the sciences, as everyone is aware, the very reverse is the case. In physics, quite apart from the new mathematico-philosophical theories which excite laymen no less than did Newtonian discoveries two hundred and fifty years ago, the last fifteen years, and (to go no further back) the twenty years again before that, were both marked by advances which changed greatly the whole course of the science. In chemistry the years 1858, 1869, 1874, 1886, 1893, 1913, each saw the birth of fundamental discoveries. And besides such changes *per saltum*, the weekly influx of published discovery—great or small, pioneering or embellishing, but all new—leaves the science different every year, and every breaking-forth in one science has its

repercussion upon others. If Cavendish or Davy were to return from Llyslum to sit a paper for a final Honours degree in chemistry to-day, could they so much as make a beginning? Even Bunsen, who died barely thirty-two years ago, would stump out after half an hour.

Now if we take this crucial point during a scientific training—the final Honours degree-examination—it comes at the end of three (sometimes four) years of the student's residence at the university, just as it did a generation or two ago, but the quantity of matter now required to be covered by the candidate is far more than it was. In my own subject I should guess that the mere volume of knowledge reckoned as of the first importance for the degree-student has doubled during the present century, one generation of men, ten generations of university students, and it is significant for school policy the whole lifetime of the Board of Education, which has still to catch up with older tendencies let alone keeping pace with new. No branch of natural science will ever cease to expand, and expand furiously, and with this awful fact before us, what is going to be done about it in our future degree-courses?

The tide of science is mounting now more swiftly than at any time in human history, and while civilization continues it will never ebb, and we have reached the moment when its flood can no longer be pent behind the barrier of a degree-examination. Indeed, that moment has already passed, for what employer, either academical or industrial or of the State scientific services, will now engage any Honours graduate who has not gone on with two years of postgraduate university research, and proved himself in it? The Honours B Sc is by itself of no professional use, the Ph D, or at any rate the work which leads up to it, is.

I must not linger over this vital question, but we must note that any large educational policy which attempts to help the supply of trained scientific men must henceforth contemplate a period of university residence lasting not three years, but five. It is not merely that five years would

be desirable; five years are in fact already obligatory for effective professional qualification.¹

We who carry on Honours courses at the university all have different methods, and rightly so. But we all have a common battle to fight against one result of this swelling flood of our various sciences. In these inelastic three years we are apt to feel so much that we must "get in" this topic and that, and surely cannot let our students go out without having heard lectures on that other, that we have great difficulty in not defeating our own aims by overfilling the time-table. Over-lecturing means robbing the laboratory; and it means encouraging the student in what is the very antithesis of science—the "set books" habit, as opposed to real reading; but also it makes him forget that books and lectures are meant to supplement experience, not supplant it. All external examiners in my subject—and, I am told, in others likewise—have met those batches of degree-candidates from whom script after script produces the same coached-up answers from So-and-so's text-book (or else, alas! his lectures); *tours de force* of pure memory, relieved at too rare intervals by any signs of real understanding and criticism, and still more rarely by evidence drawn from the student's actual experience.

You feel inclined to quote Mr. Kipling's Tomlinson :

" This I have read in a book," he said,
" and that was told to me "

And again—

The Devil he grinned behind the bars,
and banked the fires high:
" Did ye read of that sin in a book? " said he;
and Tomlinson said, " Ay! "

I suspect that poor Tomlinson was originally a worthy schoolboy who was unnaturally pushed into an Honours course at his university and found it too much for him. Perhaps he even got enough marks to gain Honours at

¹ For statistics of advanced students see Table IV.

the time but neither heaven nor hell wanted him afterwards and moreover it was hardly fair to the real Honours men

The picture of fact which I am trying to put before you would be quite unbalanced if having shown you something of the university courses I neglected the foundations upon which they are built

I have pointed out how the rapidly rising tide of knowledge in a science has in our time begun to burst through the barrier of the Honours degree examination and have urged the need for a free and practical recognition of this Meanwhile however, the damming up process at one end has rolled back at the other some of the flood beyond the universities into the schools which have thus found themselves more and more submerged in the deep waters of

premature specialization The underlying cause is, as I have said inevitable irresistible and increasing in strength we can therefore have no hope of it reaching an equilibrium with its educational consequences, unless we consciously alter the educational conditions and do so without delay Within the university the changes which I believe necessary are on the one hand the transference to three-year Pass courses of many who now are forced into Honours usually by reason of the Burnham Scale on the other hand, the official and private admission of the fact that to secure professional qualification in a science requires five years—three or four before the full examination, two or one more of research and free reading before the final recognition These two changes together would enable us to transfer from the schools a great deal of the burden of specialization which they rightly deplore This specialization has been increasingly felt and publicly lamented and debated for years but I think no really important executive body has yet taken practical steps to rectify it on a wide scale and meanwhile it has inevitably increased In the diagnosis and the practical remedies

which I have here outlined the active steps would be taken by the universities preferably in concert and it may at first sight be asked why should the universities take all this trouble in order to get schools out of a theoretical difficulty? Well enough has perhaps already been said in this address of the troubles felt by universities themselves under their present system to justify a change in that system they would get themselves out of many difficulties Yet there is more

The universities have a right to stipulate that all their entering students shall have received a school education which shall at least give them—to use words which the Cambridge Syndicate uses of a more adult stage—a body of information which will fit them to take an intelligent interest in life In order to ensure this and with due regard to the youth of the would be entrants universities have had their several matriculation examinations Now however these tests have very largely been abrogated in favour of one or other (or both) of the School Certificate examinations and there are certain aspects of these certifying tests which (however familiar they may be to many) I should like to dwell upon

Consider first the School Certificate The various boards which control this throughout the country are manned chiefly by university delegates but they have to legislate for a very wide diversity of candidates relatively few of whom will ever contemplate entering a university Some 60 000 pupils take School Certificates every year, against 10 000 who enter universities The needs of the five-sixths might be met and the ability of the academic one-sixth might be attested sufficiently if matriculation-exemption were granted for performances showing a higher understanding, and for subjects covering a broader range than for simple certification In point of fact a somewhat higher standard of marks scored ('credit' as against a simple "pass") is what is exacted The breadth of subjects studied is, I think, much the same for the average matriculation-exemption as for the simple certificate Broad as it is in theory, I would ask your patience to look

for a moment at the actual choice of studies, and in doing so it is especially important to remember that though the certificate is not actually handed to a candidate under sixteen years of age, the average age of taking part in the examination is, I understand, about fifteen and three-quarters.

I have tabulated (Table V) for June, 1929—a truly typical year of recent times—the list of subjects studied, and for each subject the number of candidates who took it, expressing that number as a percentage of the aggregate of candidates in all subjects together. Further, I have given these figures for two sets of candidates. The first column is for the Oxford and Cambridge Board's tests, and consists essentially of boys from the recognized Public Schools represented at the Headmasters' Conference. Included with them however, to the extent of about 8 per cent of the candidates, are girls from various schools, and a fairly high proportion—about 20 per cent—of candidates who came from Secondary Schools. The second column of figures is for all the remaining candidates in England and Wales, irrespectively of which Board's examinations they took. 87 per cent of them are from Secondary Schools. The two columns, then, refer to

- (1) Almost wholly boys, three-quarters of them Public School boys and covering all the Public Schools
- (2) Boys and girls in about equal proportions, nine-tenths of them from Secondary Schools, and covering almost all of the Secondary Schools of England and Wales

It will be seen that English, French, History, and Elementary Mathematics are studied by almost everyone up to this stage. As to Latin, two-thirds of the Public School boys take it, less than forty per cent of the Secondary pupils do so. In Greek the discrepancy is greater still. On the other hand, Geography is taken by over two-thirds of the Secondary pupils and by under one-third of the others. Before noticing specially the scientific

subjects, we may observe the very marked contrasts shown under the entries for Drawing or Art (44 per cent of Secondary boys and girls, 6 per cent of Public School boys), no doubt this is connected with the much higher proportion of girls among the Secondary pupils, which affects Botany in a similar way I shrink from inferring that painting flowers may still be with us as a polite female accomplishment !

The paucity of pupils in German only one in eight of Public School boys, only one in sixteen of Secondary pupils—strikes one with dismay I have no sentimental bias in this direction, rather the contrary, surely, however, for any professional man and for any business man German should rank level with French? Quite apart from any question of the relative values of the two literatures, it is certain that to be unable to read German, or to read it only painfully, is to be cut off from quite half of the learning and work of Europe One is constantly struck with this lamentable fact, as well among the younger generation of scientific people as among many of an older generation of literati How it may affect commerce I do not know, though anyone can guess, but I do plead, it only on utilitarian grounds, for schools to do their very utmost to get rid of the clashing "Greek or German or Chemistry" entry which so often occurs in their timetables, and which prevents a very large number of pupils from beginning German at the very age when they can with least difficulty attack it Personally I would willingly see sacrificed for this purpose part of the French, or all of the Chemistry—none of the English and Latin!—now being studied at the School Certificate level You will produce better students of French, of Greek, and of any other language, better chemists, and even (heaven help us!) better "Salesmanship" True, the training at our universities of English men and women as teachers of German must be made to increase if this is to be done, it is extraordinary to find that in 1929, for instance, out of some 4,600 Honours graduates (and notwithstanding the Burnham Scale) only 34 took German as a final

subject The number who took French was 428

Regarding the scientific subjects in the list, as a chemist I deplore the extraordinary number of children well under sixteen who study chemistry. That simple science must be taught to all of them goes without saying, but for young people under sixteen, to differentiate and to develop the branches of physical science as much as is done strikes me as quite artificial. Here we have, in the Secondary Schools, only 15 per cent taking General Science — the Public Schools are not quite as bad, only 18 per cent taking a composite "Physics and Chemistry" as against the much more reasonable 25 per cent of what may be classed as Public School candidates and the very low proportion of one per cent or less taking Biology, in either kind of school. On the other hand, no fewer than 43 per cent of the Secondary School pupils of ages from eleven onwards, take chemistry as a whole subject. A number of them it would seem either do not study any other science, or else study some specialized subdivisions of Physics.

Let me make no bones about this early juvenile school chemistry: a great deal of it is worth very little indeed. A great deal of it is taught by those unlucky (because misdirected) persons, the Honours graduates in chemistry, who ought to have been given a good broad Pass course which would have afforded them a reasonable perspective. It is in no way their fault if you turn out a specialist to teach youngsters, can he be blamed if he transmits the only thing you have equipped him with? I make no apology for selecting chemistry for special comment, because the universities produce far more Honours graduates in chemistry alone than in any other experimental science and nearly as many as in all the other experimental sciences put together. (In less favoured sciences the problem is not nearly as acute.) It is the legacy of a mistaken parental idea that chemistry is a paying profession with plenty of openings attainable after a three-year course, and this mistake, coupled with the Burnham Scale, has on the one hand cast upon the schools from

the university a great many stickit chemists and on the other has both encouraged and enabled the schools to generate still more of them I feel so certain that all this is true and that much harm is being done by it that plain speaking is the only stimulus to action the matter really does need to be brought to public notice

To sum up the Schools Certificate in its function is a university entrance examination I believe it is widely felt that it is broad enough subject to the definite criticisms I have made but that it measures general culture at too early an age to warrant academic suitability later on

The Higher School Certificate on the other hand as the most important substitute for the university matriculation test needs broadening this is definitely held by a great number of those who are most nearly concerned with it The statistical facts as to choice of subjects presented much as for the ordinary School Certificates are given in Table VI at the end but a more important fact is this In many of our universities though not in all of them the possession of a Higher Certificate in Science is more than a qualification for entrance It exempts its holder from some or all of the first (Intermediate) year of university work and so enables him to begin an H hours course in a science Now it is an uncomfortably frequent experience in those provincial universities which draw much upon Secondary Schools that students peter out after about fifteen or eighteen months and the reason for this distressing phenomenon is quite plain The achievement of a Higher Certificate is nearly always a heavy effort naturally but in all these particular cases it was won through memory coaching and by dependence to an extraordinary degree on the *ipse dixit* of masters and text books No examination yet invented can quite frustrate the resolute memorizer but one of the hardest tasks of a university Honours teacher is to rid the average student of to-day of the ingrained notion that the teacher's word is the alpha and omega of knowledge to make him realize that things and events not persons and books are the source of scientific information that abstract theories and

important generalizations in his own science are valueless to him, unless he can both derive them from observed fact, and conversely, apply them to observed fact. A student who has been filled with inductions of which the premises are beyond the nature of his practical experience, has been well set on the road that leads him to the antipodes of science. With students brought up in this way—and they are very, very many—our weary task is to make them replace the attitude expressed by Mr. Hilaire Belloc :

And it must be so, because
Dr Dumble said it was,

by the free principle upon which the whole of science is founded :

Nullus addictus surare in verba magistri.

There is much more, of a constructive nature, to be said concerning university entrance tests; but I shall stop. You will not, I hope, accuse me of Jeremiah-like complainings.. I know that the succession of educational sieves through which we put youth must always leave a fairly large residuum at each stage, else there would be no need to have sieves at all. What I undertook to discuss in this lecture, however, was "problems"; and in education, a problem means something to put right. That is why I have emphasized, with as much sense of proportion as I can command, the main things which appear to me to need putting right. The system of sieves as it works at present lets through—*forces* through—more material from stage to stage than would pass of its own accord, and the finer meshes are getting clogged in consequence; while material which should be retained as valuable is being cast away as dross because it gets into the wrong receptacle.

I would sum up the practical remedies which I have here partly surveyed, thus :

- (1) Broaden and simplify the elementary science that is now taught up to School Certificate level, incidentally, foster German at this period. Finally abandon the School Certificate as a sufficient criterion of suitability for university entrance
- (2) Widen the scope of the subjects required for a Higher School Certificate, lessening their intensity accordingly, and keeping to the fore English, especially, and modern languages also. Utilize the results for university entrance to an ordinary first year
- (3) Reform the Pass courses in science in the ways outlined, transfer to them many good students who at present enter Honours especially for school-teaching purposes, provided that the Board of Education will correspondingly change its present preference for "good Honours degrees" to a preference for "Pass degrees with distinction"
- (4) Recognize, both parentally and officially, that an Honours science degree is meant for those who will practise a science, and that the present state and future growth of the sciences demands university residence lasting five years before the student can attain professional status for this purpose

Much that I have said is common talk, some points may be contested, not all of it applies to each institution, I have intentionally ignored questions of science for medicine and engineering, and obviously much important detail has had to be passed over. But I have tried to put before you a coherent view of what ought to be, as well as insisting on what ought not to be. The future of our nation and others depends as much on the spread of accurate thinking as it does on the spread of material powers, and nothing is more important for our destiny than the right use of scientific education, which compasses both

APPENDIX.

POINTS BROUGHT OUT BY THE STATISTICS

TABLE I shows how in late years Honours graduations have risen and Pass degrees have fallen to a level number in England and Wales. The two lowest sections of the table put the relations of Honours to Pass concisely.

TABLE II refers to Honours graduations alone (for England, Scotland and Wales) and shows the changes in these during the past four years in each of the main faculties or groups of faculties. Those in Pure Arts form about a half of the whole, those in Pure Sciences form about a quarter and have been increasing slowly and steadily.

TABLE III shows these same graduations in Pure Science alone in detail in order that their distributions among subjects may be seen. It will be noted that Mathematics, Physics and Chemistry between them account for over three quarters and that there has been a definite fall in chemical graduations and a rise in mathematical, each of these two now accounting for one third of the graduations.

TABLE IV refers to Advanced students only i.e. essentially postgraduate. Section A shows that in the aggregate (all faculties) the numbers of these have tended to rise lately, those in the Pure Sciences having had no definite trend but forming about 45 per cent of the whole. The distribution of postgraduate science students among the main branches of science is shown in Section B. Here it will be noted that one half of them are chemists. Compared with the distributions among the Honours graduations (Table III) Mathematics occupies relatively few postgraduate workers while the other sciences provide about the same proportions of the advanced students as they do of the Honours graduates. The advanced students are partly composed of graduates of universities outside Britain and are thus not wholly drawn from the persons enumerated in Tables I-III.

TABLES V and VI refer to work in schools and are commented upon in the text pp. 19-23.

The sources of the data here tabulated are for Tables I to IV the annual *Returns from Universities and University Colleges* issued by the University Grants Committee through H.M. Stationery Office for Tables V and VI the annual lists and statistics published by the Oxford and Cambridge Schools Examinations Board and the annual report published by the Board of Education *Education in 1929*.

The figures given here have mostly been brought together and reckoned arithmetically from the data in these publications not copied directly. I am therefore responsible for any numerical slips which are not present in the original publications.

TABLE I
ENGLAND AND WALES
HONOURS AND PASS DEGREES

Year ending June	1924	1925	1926	1927	1928	1929	1930
Total full-time students	32,430	32,024	31,963	32,256	32,551	33,362	34,411
Hon. & Pass Degrees.							
Men	5043	4550	4396	4377	4431	4555	4739
Women	2422	2052	2054	2042	2106	2040	1823
Total	7465	6602	6450	6419	6537	6595	6562
Hons. Degrees							
Men	2912	2695	2525	2564	2715	2844	3038
Women	1439	1133	1149*	1423	1513	1455	1308
Total	4351	3828	3674	3987	4228	4299	4346
Pass Degrees.							
Men	2131	1855	1871	1813	1716	1711	1701
Women	983	919	905*	619	593	585	515
Total	3114	2774	2776	2432	2309	2296	2216
Excess of Hons. over Pass Degr.							
Men	781	840	654	751	999	1133	1337
Women	456	214	244*	804	920	870	793
Total	1237	1054	898	1555	1919	2003	2130
Ratio of Hons. to Pass.							
Men	1.37	1.45	1.35	1.41	1.58	1.66	1.79
Women	1.46	1.23	1.27*	2.30	2.55	2.49	2.54
Total	1.40	1.38	1.33	1.64	1.83	1.87	1.96

* Before 1927, the classification of some of the women graduates as Pass or Honours was not rigid, a comparatively small number of them were probably rated as "Pass" when they were actually Honours graduates.

TABLE II
ENGLAND SCOTLAND AND WALES*
ANALYSIS OF HONOURS DEGREES ACCORDING TO
FACULTIES

Year ending June		1927	1928	1929	1930
Pure Arts	Men	1302	1273	1264	1462
	Women	944	1037	1047	1133
	Total	2246	2310	2311	2595
Law Econ Educ etc	Men	260	430	485	527
	Women	21	24	38	40
	Total	281	454	523	567
Total Arts, etc	Men	1582	1703	1749	1989
	Women	985	1061	1085	1173
	Total	2527	2764	2834	3162
Pure Sciences	Men	919	944	994	1027
	Women	270	275	258	271
	Total	1189	1219	1252	1298
Med Eng Agric etc	Men	464	448	466	442
	Women	9	13	19	26
	Total	473	461	485	468
Total Sciences, etc	Men	1383	1392	1460	1469
	Women	279	288	277	297
	Total	1662	1680	1737	1766
AGGREGATES	Men	2945	3095	3209	3458
	Women	1244	1349	1362	1470
	Total	4189	4444	4571	4928

* Separate figures for England and Wales are not obtainable from the published data.

TABLE III
ENGLAND SCOTI AND, AND WALES*
HONOURS DEGREES IN PURE SCIENCE, ACCORDING TO SUBJECTS

Percentage Distributions

	1927	1928	1929	1930
	Percentages of the year's Honours Graduates *			
†Mathematics	27 4	27 3	29 9	31 9
Physics	17 4	16 0	13 6	15 8
‡Chemistry	40 4	37 4	35 8	31 9
Botany	9 1	8 9	8 5	9 0
Zoology	1 5	3 2	4 0	3 3
Physiology	1 7	5 7	5 4	5 6
Geology	2 5	1 5	2 8	2 5
	100 0	100 0	100 0	100 0
Actual No so specified	815	971	991	1002

* Counting only those whose degrees were in a named science
 General Honours and Natural Sciences are not included in
 this table but they are in Table II

† With which are put Mathematical Physics and Astronomy

‡ Excluding technological chemistry

TABLE IV (A) AND (B)
 ENGLAND SCOTI AND AND WALES
 FULL-TIME ADVANCED STUDENTS

(A) General

Year ending June	1924	1925	1926	1927	1928	1929	1930
Total full time students	42 892	41 794	41 606	42 354	43 262	44 309	45 603
Advanced all subjects	2 137	2 123	2 063	1 993	2 044	2 082	2 128
Advanced Pure Sciences only			897	863	870	872	883

*(B) Percentage Distributions
 of full-time Advanced Students in Pure Science according
 to subjects*

Mathematical			5 6	7 2	7 5	7 5
Physics			15 5	18 9	21 3	16 0
Chemistry			52 9	48 5	46 9	50 3
Botany			10 0	11 5	8 4	9 9
Zoological			5 6	6 3	7 4	7 5
Physiology			3 9	3 1	4 4	4 6
Geological			6 6	4 4	4 0	4 1
	100 0	100 0	100 0	100 0	100 0	100 0
Actual number so specified*			853	858	867	875

* The discrepancies between this row of figures and that at the foot of (A) above are due to the inclusion in (A) of advanced students in unnamed Pure Sciences

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TABLE V
SCHOOL CERTIFICATE CANDIDATURES
July, 1929

Subject	Percentage of total candidates offering the subject	
	(1) Oxford and Cambridge Board	(2) Other Boards
English	96	100
History	84	88
Geography	32	70
Scripture or Religious Knowledge	56	22
Latin	67	40
Greek	18	2
French	99	96
German	12	6½
Italian	2	
Russian	0	
Spanish	3	1
Arabic	0	
Welsh		5
Mathematics, Elem	99	93
Higher	24	3½
General Science	11	1½
Natural History		1
Physics and Chemistry	25	3
Biology	½	1
Mechanics		4
Physics	19	27½
Chemistry	22	43
Zoology	½	
Botany	3	26
Geology	½	
Heat, Light, Sound		6
Electricity and Magnetism		4
Music	½	1½
Drawing, Art	6	44
Domestic Science		1
Economics	—	1
Number of candidates	6,774	52,810
Includes from Sec Schools	1,588	45,844
" Others . . .	5,208	6,966

TABLE VI
HIGHER SCHOOL CERTIFICATE
CANDIDATURES

July, 1929

Group	Percentage of total candidates offering the Group.	
	(1) Oxford and Cambridge Board	(2) Other Boards
Classical	24.3	4.0
Modern Studies	35.4*	52.7
Total " Arts " ...	—	59.7
Mathematics	13.7	2.7
Science	26.6	39.0
Total " Science "	—	41.7
-	100.0	98.5†
Total No. of candidates	2,184†	6,905

* Of whom 7.6 took a Classical Language together with, e.g., English or History.

† Including 758 candidates also included under column (2).

‡ The remaining 1.5 per cent took Group E in the London University's examinations, in which Geography is the principal subject.

THE THEORY OF THE COLD-FRAME

BY PROF G W TODD M A D SC I INST I

It appears that no attempt has ever been made to estimate greenhouse temperatures theoretically by the application of the established laws of radiation. In view of the fact that the greenhouse is an indispensable part of the horticulturist's equipment this absence of investigation is surprising. Still more surprising is the absence of systematic temperature observations for varying conditions of external temperature, sun altitude, sky wind, and so on.

The object of this paper is to develop an equation which gives the relation between uncovered-soil temperature and glass-covered soil temperature in terms of the radiation incident on the Earth's surface and to calculate from it the temperatures likely to be attained in a cold-frame or unheated greenhouse. The method could be used to test the relative values of other transparent materials when used as greenhouse coverings.

Nature of the problem

Let us get an idea of the nature of the problem by considering an ideal case. Assume an infinitely extended horizontal sheet of glass over a horizontal layer of soil, the latter being considered a full radiator. Let there be no heat interchanges except by radiation.

Let the rate at which energy of radiation (sunlight) falls normally on the glass be S . Of this rS will be reflected, aS will be absorbed, and tS will be transmitted through the glass. Hence

$$r + a + t = 1$$

Let the radiation from the soil be R per sq cm per second. When this reaches the glass, $r_1 R$ will be reflected back to the soil, $a_1 R$ will be absorbed by the glass, and $t_1 R$ will be transmitted through the glass. Again

$$r_1 + a_1 + t_1 = 1$$

Now we may regard each unit area of the soil as receiving from, and emitting to, each unit of glass. Thus the glass absorbs aS from above and a_1R from below, i.e., a total of $aS + a_1R$, and if equilibrium conditions exist, the glass will also radiate this amount. For the sake of argument let us assume that it radiates equal quantities up and down. In equilibrium the radiation from the soil will be equal to the receipt from above, i.e.,

$$R = tS + r_1R + \frac{1}{2}(aS + a_1R)$$

$$= \frac{t + \frac{a}{2}}{a_1} S \quad \text{since } r_1 = 1 - a_1 - t_1$$

$$t_1 + \frac{a_1}{2}$$

Now if θ is the absolute temperature of the soil when the glass is absent, and θ' the absolute temperature when the glass is above the soil, then Stefan's law gives

$$\frac{R}{S} = \left(\frac{\theta'}{\theta}\right)^4$$

$$\text{so that } \frac{\theta'}{\theta} = \left(\frac{t + \frac{a}{2}}{t_1 + \frac{a_1}{2}}\right)^{\frac{1}{4}}$$

Glass transmits a very high percentage of visible radiation and therefore absorbs a very small fraction. For approximate estimation we will take $t = 96$ and $a = 02$. On the other hand, practically no low temperature or long-wave radiation is transmitted or reflected. It is mostly absorbed by glass. We will therefore take $t_1 = 0$ and $a_1 = 1$. Putting these values into the last equation gives

$$\frac{\theta'}{\theta} = \left(\frac{97}{5}\right)^{\frac{1}{4}} = 1.18$$

Thus if the soil temperature without the glass cover is 10° C (283° A.), the temperature of the soil under glass will be $(1.18 \times 283)^\circ \text{ A.}$ or 61° C.

We have ignored the possibility of multiple reflections between soil and glass and we have made the assumption that the glass disposes of its absorbed radiation equally upwards and downwards

Let the soil reflect a fraction ρ of the short-wave radiation which reaches it via the glass. Taking account of the first reflection only, the equilibrium equation becomes

$$R - tS = \rho tS + r_1 R + \frac{1}{2}(aS + \rho tS + a_1 R)$$

$$\text{or } R = \left\{ \frac{t + \frac{a}{2}}{\frac{t_1 + \frac{a_1}{2}}{2} + \rho t} + \rho t \frac{\frac{a}{2} - 1}{\frac{t_1 + \frac{a_1}{2}}{2}} \right\} S$$

Taking the high value 0.01 for ρ , and giving t , t_1 , a , a_1 , the same values as before, we find

$$\frac{\theta^1}{\theta} = \left(\frac{97}{5} - 0.018 \right)^{\frac{1}{2}} = 1.18$$

which is imperceptibly less than the previous result. We shall therefore ignore multiple reflections between soil and glass.

If the glass emission is not equally divided up and down, let the amount sent down be $\frac{1}{n}(aS + a_1 R)$. Then we find

$$\frac{\theta^1}{\theta} = \left(\frac{t + \frac{a}{n}}{\frac{t_1 + \frac{n-1}{n}a_1}{n}} \right)^{\frac{1}{2}}$$

In all probability, however, n will not be very different from 2, and we propose to take that value in all that follows.

Further considerations

Having indicated a method of attack on the problem of determining the temperature inside a cold-frame by a preliminary examination of a somewhat ideal case, we

now proceed to a more quantitative examination. In the preliminary examination we have assumed the glass to have constant coefficients of transmission, absorption and reflection for the external incident radiation, and also constant but different coefficients for the soil radiation. Actually these coefficients vary continuously with the wave-length. The glass thickness must be a factor influencing the values of the absorption and transmission coefficients. We have to consider also the effect of the Sun's altitude on the total radiation incident on the glass of the cold-frame. The atmosphere itself sends radiation down to the glass, and like the glass, it also has a "cold-frame" effect on the soil. Many other factors affecting the inside temperature of a cold-frame can be added to those just mentioned, but we shall dismiss most of them because their effects are insignificant.

We will consider first the incidence of radiation due to the atmosphere. This will vary with the temperature and with the state of the sky (whether cloudy or clear). We shall deal with it, for a clear sky and constant atmospheric temperature, by introducing a constant into the equilibrium equation. If the radiation incident on the glass from the atmosphere is K , since it is low-temperature or long-wave radiation, we put it into the equilibrium equation thus

$$R = tS + t_1K + r_1R + \frac{1}{2}(aS + a_1R + a_1K)$$

$$\text{whence } R = S \frac{t + \frac{a}{2}}{t_1 + \frac{a_1}{2}} + K$$

$$\text{and } \left(\frac{\theta'}{\theta}\right)^+ = \frac{R}{S+K} = \frac{S}{S+K} \frac{t + \frac{a}{2}}{t_1 + \frac{a_1}{2}} + \frac{K}{S+K}$$

Let us now examine the variation of the coefficients of transmission and absorption with variation in wave-length.

Let the coefficients for a wave-length λ be t_λ , a_λ and r_λ , then we have $t_\lambda + a_\lambda + r_\lambda = 1$. Denoting the incident monochromatic radiation from the sun by S_λ the total Sun radiation falling on the glass is

$$S = \int_0^\infty S_\lambda d\lambda$$

The glass transmits $\int_0^\infty t_\lambda S_\lambda d\lambda$

and it absorbs $\int_0^\infty a_\lambda S_\lambda d\lambda$

The radiation coming up from the soil is

$$R = \int_0^\infty R_\lambda d\lambda$$

and of this, the glass transmits

$$\int_0^\infty t_\lambda R_\lambda d\lambda \text{ and absorbs } \int_0^\infty a_\lambda R_\lambda d\lambda$$

Thus the radiation absorbed by the glass from above and below is

$$\int_0^\infty a_\lambda S_\lambda d\lambda + \int_0^\infty a_\lambda R_\lambda d\lambda + a_i K$$

Equating the receipt by the soil to its emission, we have for equilibrium conditions

$$\int_0^\infty R_\lambda d\lambda = \int_0^\infty t_\lambda S_\lambda d\lambda + t_i K + \int_0^\infty r_\lambda R_\lambda d\lambda + \frac{1}{2} \left[\int_0^\infty a_\lambda S_\lambda d\lambda + \int_0^\infty a_\lambda R_\lambda d\lambda + a_i K \right]$$

neglecting losses by conduction and convection Rearranging the terms gives

$$\int_0^\infty \left(t_\lambda + \frac{a_\lambda}{2} \right) R_\lambda d\lambda = \int_0^\infty \left(t_\lambda + \frac{a_\lambda}{2} \right) S_\lambda d\lambda + \left(t_i + \frac{a_i}{2} \right) K$$

If the relations between the coefficients and wavelength were known, it might be possible to solve this equation. In the absence of known relations, we must attempt a graphical solution from the available information.

Graphical method of solution

In the first place we have to remember that the Earth's atmosphere absorbs a considerable proportion of the Sun's radiation before it reaches the cold frame. The absorption is mainly in the short-wave region. Using the results of Langley and Abbot we have plotted fig 1, showing the fraction transmitted for zenith Sun. The curve has been

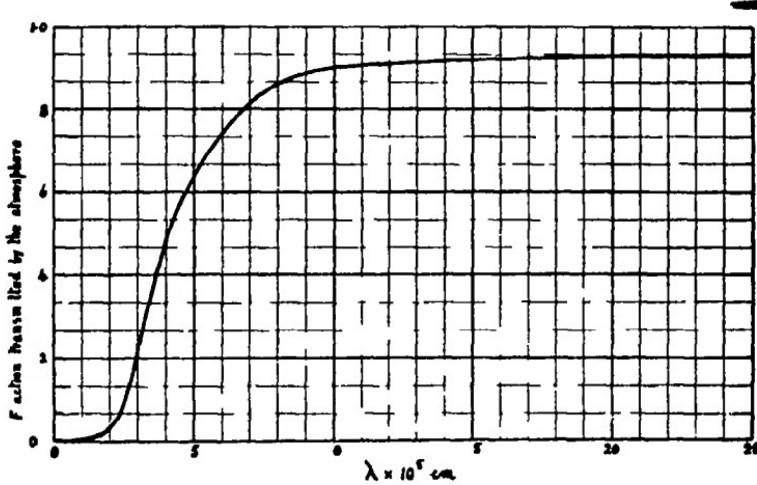


Fig 1

extrapolated in both directions on the assumption that the very short waves are completely absorbed and the very long waves easily transmitted by the atmosphere

The upper continuous curve in fig 2 gives the energy emission in ergs per sq cm per sec from a body at 6000° Abs , i.e., the emission from the surface of the Sun, and it has been calculated from Planck's well-known formula

$$E_\lambda = 8\pi\lambda^{-4} \frac{h\nu}{h\nu/kT} e^{-1}$$

Fig 3 shows the emission from a body at 300° Abs . (an easy figure to take for the temperature of the Earth's surface) calculated from the same formula

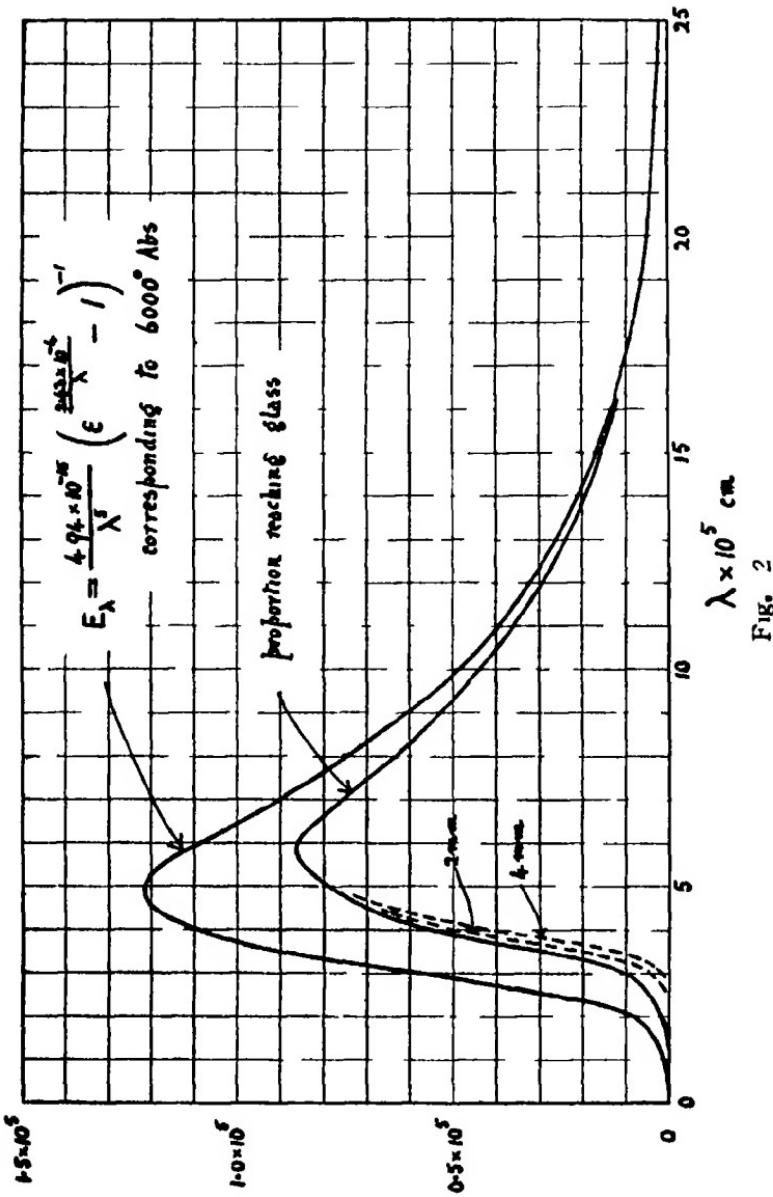


Fig. 2

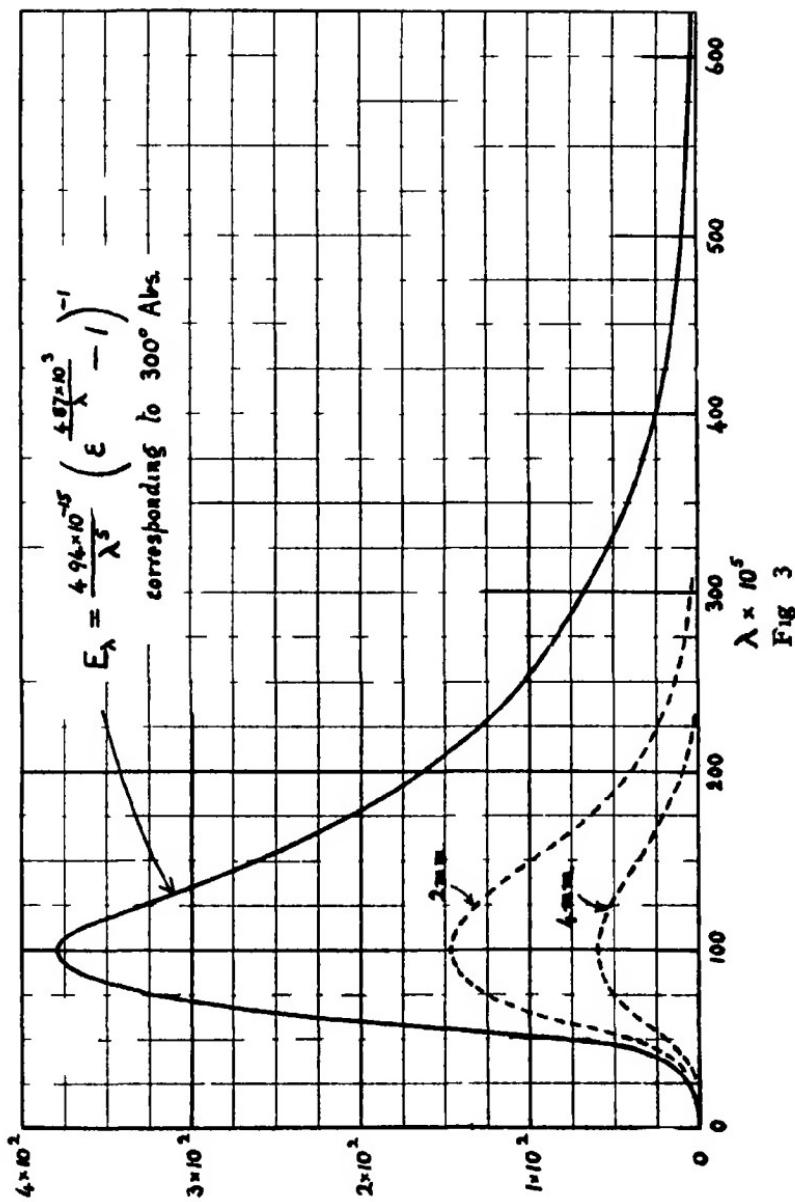


Fig. 3

The second continuous curve in fig. 2 gives the proportion of radiation reaching the glass after atmospheric absorption, calculated from fig. 1. The integral $\int_0^\infty S_\lambda \cdot d\lambda$ is proportional to the area under this curve.

If it is required to make comparisons between S_λ and R_λ in figs. 2 and 3, the ordinates of fig. 2 must be reduced to give radiation incident on unit surface of the Earth. Taking the radius of the Sun as 0.695×10^{11} cm., and its distance from the Earth as 1.494×10^{13} cm., the radiation from 1 sq.cm. of the Sun's surface falls on $(1.494 \times 10^{13} / 0.695 \times 10^{11})^2$ sq.cm. of the Earth's surface. The ordinates in fig. 2 must therefore be multiplied by 0.216×10^{-4} .

Experimental investigation concerning the transmission of radiation through glass covers a region of wave-lengths

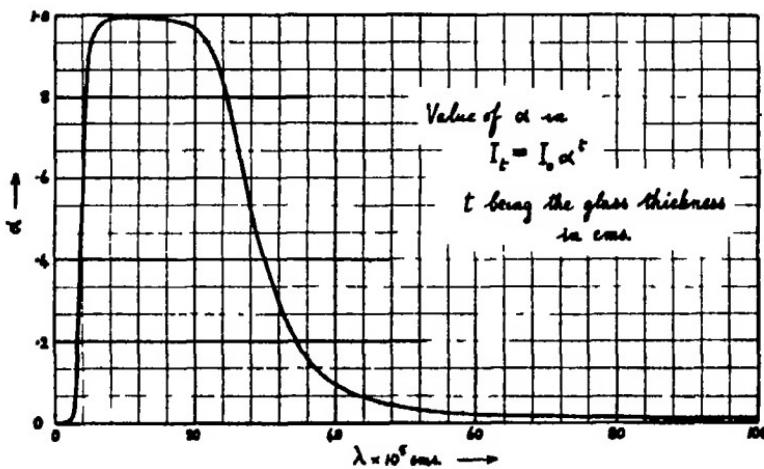


Fig. 4.

from the ultra-violet to about 4μ in the infrared. Expressing the results, for ordinary glass, in the form

$$I_t = I_0 \alpha^t$$

where I is intensity and t is the thickness of the glass, the values of α for different wave-lengths are shown in fig. 4. The curve beyond 4μ is purely fictitious because of the absence of data.

By using fig. 4 we are able to calculate the radiation transmitted through glass of known thickness when the character of the incident radiation is known. The dotted curves in figs. 2 and 3 have been so calculated and they show the radiation transmitted through glass of 2 mm. and 4 mm. thickness. It will be observed (fig. 2) that practically all the radiation, incident from the outside on to the glass, is transmitted. The areas enclosed give the total energy values.

$$\text{Let us put } \int_0^\infty t_\lambda S_\lambda \cdot d\lambda = t \int_0^\infty S_\lambda \cdot d\lambda$$

$$\text{and } \int_0^\infty a_\lambda S_\lambda \cdot d\lambda = a \int_0^\infty S_\lambda \cdot d\lambda$$

If we neglect reflection as insignificant, so that $a = 1 - t$, we need only estimate $\int_0^\infty t_\lambda S_\lambda \cdot d\lambda$ and $\int_0^\infty S_\lambda \cdot d\lambda$ from fig. 2 in order to get both t and a .

In a similar manner we can find from fig. 3 the values of t_i and a_i for the coefficients of transmission and absorption of the soil radiation. These latter correspond to a soil temperature of 300° Abs. and we shall assume that their values do not change appreciably for the various soil temperatures likely to be found under glass.

The "cold-frame" equation therefore becomes

$$\left(t_i + \frac{a_i}{2} \right) \int_0^\infty R_\lambda \cdot d\lambda = \left(t + \frac{a}{2} \right) \int_0^\infty S_\lambda \cdot d\lambda + \left(t_i + \frac{a_i}{2} \right) K$$

giving

$$\left(\frac{\theta^i}{\theta} \right)^4 = \frac{\int R_\lambda \cdot d\lambda}{\int S_\lambda \cdot d\lambda + K}$$

$$\begin{aligned}
 &= \frac{\int S_\lambda d\lambda}{\int S_\lambda d\lambda + K} \cdot \frac{t + \frac{a_1}{2}}{t_1 + \frac{a_1}{2}} + \frac{K}{\int S_\lambda d\lambda + K} \\
 &= \frac{1}{\int S_\lambda d\lambda + K} \left[\frac{t + \frac{a_1}{2}}{t_1 + \frac{a_1}{2}} \int S_\lambda d\lambda + K \right]
 \end{aligned}$$

We now proceed to the graphical determination of the constants from figs 2 and 3

From fig. 2

The area of the curve for glass of 2 mm thickness is

$$\int_0^\infty t_\lambda S_\lambda d\lambda = 640 \text{ small squares}$$

and the area for glass of 4 mm thickness is 620 small squares We find also that

$$\int_0^\infty S_\lambda d\lambda = 650 \text{ small squares}$$

$$\text{Thus } t \text{ for } 2\text{mm glass} = \frac{640}{650} = 984$$

$$a \text{ } " \text{ } " \text{ } " = 016$$

$$\text{And } t \text{ for } 4\text{mm glass} = \frac{620}{650} = 953$$

$$a \text{ } " \text{ } " \text{ } " = 047$$

From fig. 3

$$\text{For glass of } 2\text{mm thickness} \int_0^\infty t_\lambda R_\lambda d\lambda = 174 \text{ small squares}$$

$$" \text{ } " \text{ } " \text{ } 4\text{mm} \text{ } " \text{ } " \text{ } " = 63 \text{ } " \text{ } " \text{ }$$

$$\text{Also } \int_0^\infty R_\lambda d\lambda = 593 \text{ small squares}$$

$$\text{Thus } t_1 \text{ for } 2\text{mm glass} = \frac{174}{593} = 293$$

$$\therefore a_1 \text{ } " \text{ } " \text{ } " = 707$$

$$\text{And } t_1 \text{ for } 4\text{mm glass} = \frac{63}{593} = .106$$

$$\therefore a_1 \text{ } " \text{ } " \text{ } " = 894$$

Taking the value of Stefan's radiation constant as 6.0×10^{-5} erg cm⁻² sec⁻¹, and the mean temperature of the Earth's surface is 280° Abs, we get

$$K = 6.0 \times 10^{-5} \times 280^4 \text{ ergs cm}^{-2} \text{ sec}^{-1} = 3.6 \times 10^3$$

The substitution of these constants in the "cold-frame" equation and the measurement of $\int S_\lambda d\lambda$ from fig. 2 will now give us the ratio of the absolute temperature of glass-covered soil to that of uncovered soil, for zenith Sun

$$\begin{aligned} \int_0^\infty S_\lambda d\lambda &= 650 \text{ small squares} \\ &= 14 \times 10^7 \text{ ergs cm}^{-2} \text{ sec}^{-1} \text{ on the} \\ &\quad \text{Earth's surface} \end{aligned}$$

Whence for 2 mm glass

$$\left(\frac{\theta'}{\theta}\right)^4 = \frac{1}{14 \times 10^7 + 3.6 \times 10^3} \left[\frac{992}{646} 14 \times 10^7 + 3.6 \times 10^3 \right]$$

$$\frac{\theta'}{\theta} = 1.09$$

And for 4 mm glass

$$\left(\frac{\theta'}{\theta}\right)^4 = \frac{1}{14 \times 10^7 + 3.6 \times 10^3} \left[\frac{976}{553} 14 \times 10^7 + 3.6 \times 10^3 \right]$$

$$\frac{\theta'}{\theta} = 1.12$$

The ratio θ'/θ appears to reach a limiting value as the thickness of the glass increases, and there is little to be gained by increasing the thickness beyond that usually found on a greenhouse or cold-frame

Effect of variation of Sun's altitude

The results we have just obtained hold only for zenith Sun. In countries where cold-frames are necessary, the maximum altitude of the Sun is considerably less than 90°, and we have now to investigate how the ratio θ'/θ is affected by atmospheric absorption varying with the altitude of the Sun. In obtaining an estimate of this effect we shall assume the atmosphere to be a homogeneous layer over the Earth's surface

Let S be the normal incidence of λ radiation on 1 sq cm then

$$S = E_\lambda f$$

where f is the fraction transmitted by the air of the radiation E_λ falling outside the Earth's atmosphere Fig 1 gives the values of f for any λ

The reception by a horizontal sq cm of rays incident at an inclination α will then be*

$$S_\alpha = E_\lambda f \left(\frac{1}{\sin \alpha} \right) \sin \alpha$$

* If h = height of the homogeneous atmosphere $S = E_\lambda e^{-kh}$ where k is the absorption coefficient If the rays travel through the atmosphere at an inclination of α to the Earth's surface then $S_\alpha = E_\lambda e^{-kh \sin \alpha}$ The inclination of the rays introduces the additional factor $\sin \alpha$

Thus the total incidence on a horizontal sq cm when the Sun is at an altitude of α is

$$\int_0^\infty E_\lambda f \left(\frac{1}{\sin \alpha} \right) \sin \alpha d\lambda$$

Since f is known from fig 1 this integral can be determined graphically for various values of α

For zenith sun i.e. $\alpha = 90^\circ$ we get from fig 1

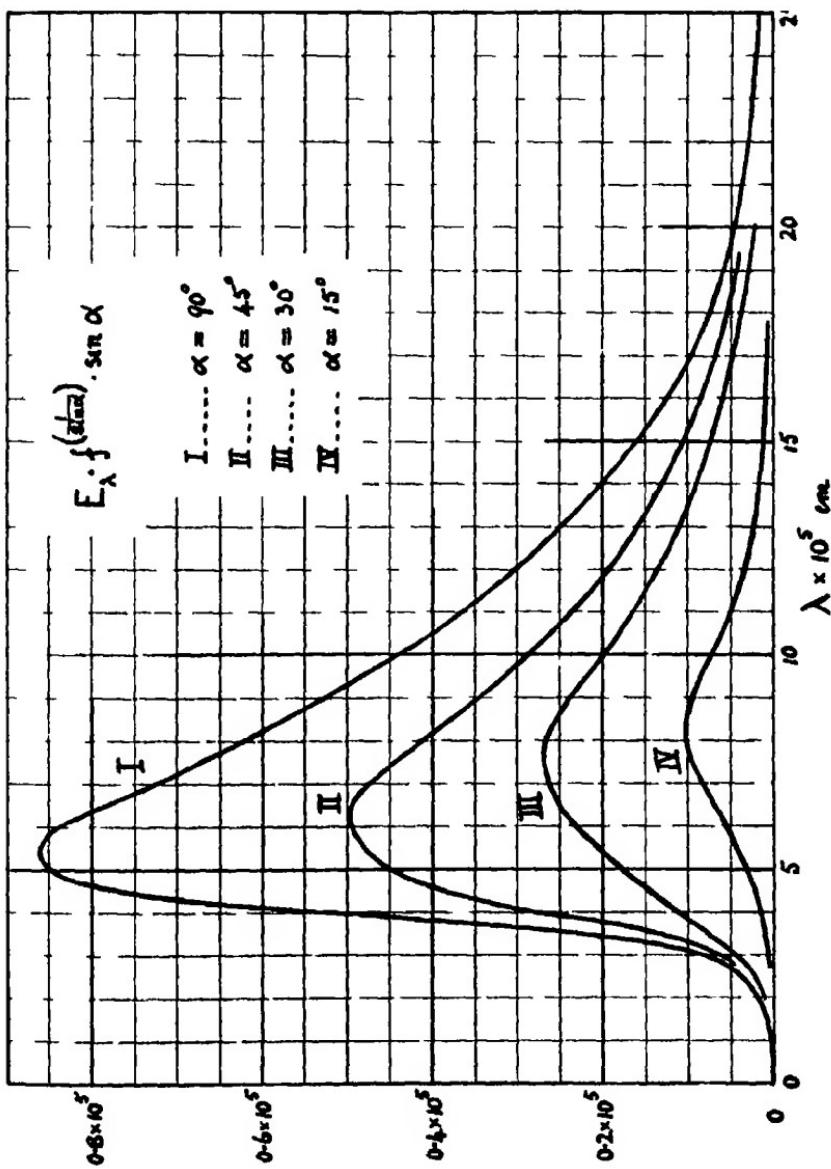
$\lambda \times 10^6$	2	4	6	8	12	24
f	03	49	73	85	91	92

For sun at 45°

$\lambda \times 10^6$	2	4	6	8	12	24
$f \left(\frac{1}{\sin \alpha} \right)$	005	26	45	56	62	63

For sun at 30°

$\lambda \times 10^6$	2	4	6	8	12	24
$f \left(\frac{1}{\sin \alpha} \right)$	0	12	21	36	41	42



	For sun at 15° (actually for sun (↑))					
$\lambda \times 10^6$	2	4	6	8	12	24
$f\left(\frac{1}{\sin \alpha}\right)$	0	0.14	0.45	1.3	17	18

The curves in fig. 5 are plotted from these figures. The areas under the curves give us the values of

$$\int_0^\infty E_\lambda f\left(\frac{1}{\sin \alpha}\right) \sin \alpha d\lambda$$

for various Sun altitudes. We find

Curve	α	Area	Rad at on
I	90	650	140×10
II	45	415	80×10
III	30	32	50×10
IV	15	60	13×10

Since most of the radiation is in the visible region the transmission and absorption constants will be practically unchanged and if the glass is thick we may ignore the increase in path through it produced by the changes in the incident angle. The substitution therefore of these radiation values in the cold frame equation will give the values of θ/θ for the altitudes taken.

The result is (for $\theta = 280^\circ$ A = 7° C)

for 2 mm glass

α	90	45	30	15	0
$\frac{\theta}{\theta}$	1.09	1.08	1.07	1.03	1.00

for 4 mm glass

α	90	45	30	15	0
$\frac{\theta}{\theta}$	1.12	1.11	1.09	1.04	1.00

On making similar calculations for a range of uncovered soil temperatures we arrive at the following table, from which the graphs in figs. 6 and 7 have been plotted. The upper figures in columns 3, 4, 5, 6 and 7 of the table refer to glass of 2 mm. thickness and the lower figures to glass of 4 mm. thickness.

Table giving the maximum temperature of glass-covered soil for various uncovered-soil temperatures.

Uncovered Soil temperature	K $\frac{1}{10^5}$	Glass-covered soil temperature for $a =$				
		0°	15	30°	45°	90°
—5°C	3.1	—5°C	6°C	14°C	19°C	22°C
		—5°C	7°C	22°C	27°C	30°C
0°C	3.3	0°C	8°C	19°C	23°C	25°C
		0°C	13°C	27°C	32°C	34°C
5°C	3.5	5°C	14°C	24°C	28°C	30°C
		5°C	17°C	32°C	37°C	38°C
7°C	3.6	7°C	15°C	26°C	29°C	32°C
		7°C	18°C	33°C	38°C	40°C
10°C	3.8	10°C	18°C	29°C	33°C	35°C
		10°C	23°C	38°C	41°C	44°C
15°C	4.1	15°C	24°C	35°C	38°C	41°C
		15°C	26°C	41°C	46°C	49°C
20°C	4.4	20°C	28°C	39°C	43°C	46°C
		20°C	32°C	46°C	52°C	55°C

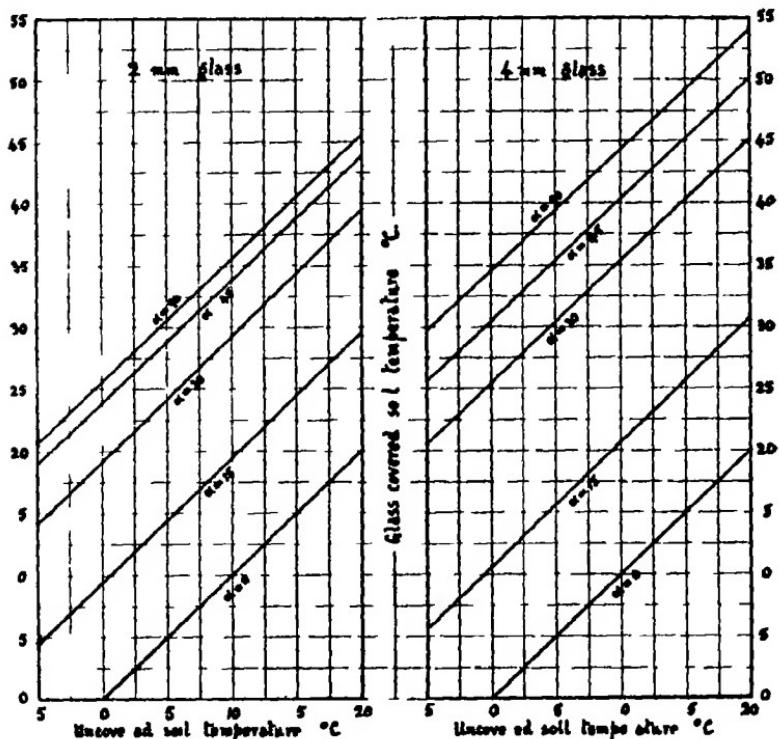
It will be observed from the curves, figs. 6 and 7, that for practical purposes the relation between glass-covered soil temperature and uncovered soil temperature is linear for constant Sun altitude, and we may write

$$T' = T + A$$

where T' is the Centigrade temperature of the glass-covered soil, T the temperature of uncovered soil, and A is a number depending on the thickness of the glass and the altitude of the Sun. The values of A are

These figures enable us to calculate the equilibrium cold frame excess-temperature at any hour of the day on

α	0	15	30	45	90
A (2mm)	0	8.5	19	23.3	25.5
A (4mm)	0	1	27	32	35



F g 6

F g 7

any date of the year and for any specified latitude An example of such calculations is provided in the self explanatory table and graphs given below The actual cold-frame-excess-temperature curves will of course be sheared over in the direction of pm times (see fig 8) on account of the temperature time lag which every cold-frame experiences This lag should be sufficient to carry a temperature excess through the night until sunrise

TABLE

Altitude (α) of Sun in latitude 53 N and the corresponding equilibrium coldframe excess temperature (A) 4mm glass

	Noon		11 & 13		10 & 14		9 & 15		8 & 16		7 & 17		6 & 18	
	α	A	α	A	α	A	α	A	α	A	α	A	α	A
Dec 22	13 6	10 1	12 5	10	9 2	7	4 2	3						
Jan 21 & Nov 22	16 9	15	15 8	14	12 4	9 1	7 2	5 1	0 5					
Feb 20 & Oct 23	25 6	23	24 4	22 1	20 7	19	15 0	12	8 1	6				
Mar 21 & Sept 23	37 3	29 1	35 8	29	31 6	27 1	25 4	23	17 1	16	9 2	7	0 2	-
Apr 20 & Aug 23	48 5	32 1	46 8	32	42 1	31	35 2	29	27 0	25	18 1	16	9 1	-
May 22 & July 21	57 4	33 1	55 7	33 1	50 1	33	42 6	31	34 1	28 1	25 1	23	16 1	14
June 21	60 4	34	58 3	34	52 7	33	45 1	34	36 4	29 1	27 4	25	18 1	16

A similar set of figures were calculated for 2mm glass and these together with those in the table are plotted in the graphs shown in fig 8

The final results are remarkably simple. Whether they represent the facts or not it is impossible to decide because of the complete absence of data respecting cold frame temperatures. There may be serious omissions in the theory. For instance the reflection of incident

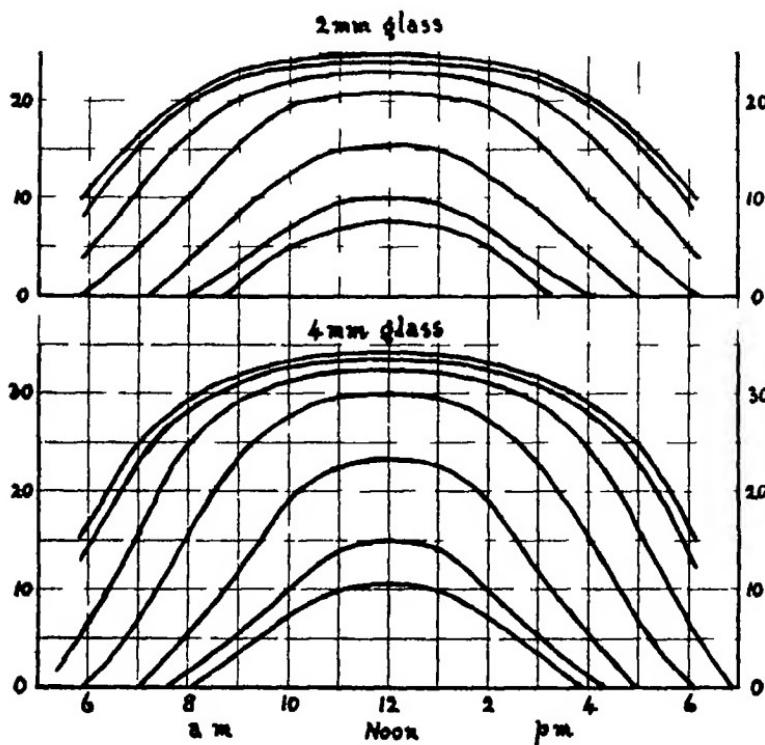


Fig 8
Equilibrium Coldframe Excess Temperature
(Degrees centigrade in Latitude 53 N)

Curves from top to bottom are for June 21 May 22 & July 21
Apr 20 & Aug 23 Mar 21 & Sept 23 Feb 20 & Oct 23
Jan 21 & Nov 22 and Dec 22 respectively

radiation from the upper surface of the glass has been regarded as unimportant. This is merely a convenience encouraged by the absence of data. Although the reflection is only a few per cent at normal incidence, it attains

considerable proportions at low Sun altitudes. The effect is compensated, however, by the fact that at small Sun altitudes the long wave radiation from the atmosphere contributes even more than the short wave radiation to the heat content of the glass-covered soil. Then again, the cooling effects of conduction and convection have been left out of the equilibrium equation.

It must be remembered that all the calculations are based on the assumption that equilibrium has been reached in full sunlight. In actual practice there will be a time-lag, characteristic of each cold-frame, depending chiefly on the heat capacity.

THE PERMIAN YELLOW SANDS OF NORTH-EAST ENGLAND.

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I. Introduction.

The formation known as the Permian Yellow Sands has hitherto not been subjected to any detailed examination in the light of modern petrological methods. Further south, in Yorkshire, the equivalent beds have been examined by Dr. H. C. Versey, whose conclusions are set out in a paper entitled "The Beds underlying the Magnesian Limestone in Yorkshire,"²⁴ and it is hoped that the present paper will serve to extend our knowledge of these beds in their more northerly development.

The area under consideration extends from Collywell Bay, near Seaton Sluice in south-east Northumberland, to Middridge in the south of Durham, being bounded on the west by the escarpment of the Magnesian Limestone, and on the east by the sea-coast. It is covered by 1-inch Sheets Nos. 15, 21, 26, 27, 32, and 33 (New Series) of the Geological Survey.

The Yellow Sands outcrop at three places in Northumberland, namely : Collywell Bay, Cullercoats Bay, and Tynemouth Cliff, while in the Durham area they occur sporadically at the base of the Magnesian Limestone escarpment throughout its length. (See map, Plate I.)

II. Previous Work on the Deposit.

The earliest description of the Permian formation in this area is that given by Winch in a paper published in the *Transactions of the Geological Society* in 1817.¹ In this paper no mention of the Yellow Sands is made, and Winch apparently assumed that the soft sandstones immediately underlying the Magnesian Limestone at Cullercoats belonged to the Coal Measures.

In 1835 Sedgwick published a very detailed description of the relations and structure of the Magnesian Limestone, in which he gave the following succession, from the base upwards

- 1 Lower Red Sandstone
- 2 Marl slate associated with grey thin bedded, and nearly compact limestone
- 2A Variously coloured mirls with thin beds of compact and shelly limestone
- 3 A great deposit of yellow magnesian limestone, often cellular and earthy sometimes hard and crystalline
- 4 Lower red marl and gypsum
- 5 Grey thin bedded limestone
- 6 Upper red sandstone
- 7 Upper red marl and gypsum

Sedgwick defined the first of these divisions the lower red sandstone as the lowest member of the group of the new red sandstone which in Yorkshire and Durham is interposed between the carboniferous order and the strata of magnesian limestone. William Smith in his geological map of Yorkshire has shown the lower red sandstone (the Pontefract Rock) as co extensive with the Magnesian limestone, and from this Sedgwick concluded that it must be unconformable with the Coal Measures, and notes that Conybeare believed it to be analogous to the Rotliegende of Germany.

In his examination of the Durham area Sedgwick found the lower beds of the limestone to be occasionally arenaceous, and in some places to rest upon and apparently to pass into a yellow, incoherent coarse, siliceous sand which he classified as a variety of his lower red sandstone group, and which he believed to be 'drift sand' resulting from the denudation of the Carboniferous strata.

This is the first definite reference to the beds which are now known as the Yellow Sands, and out of it arise several points of interest. First, Sedgwick placed them in a conformable sequence with the underlying red sandstones and the overlying magnesian limestones. Second,

he believed the material making up the deposit to be derived from the Carboniferous rocks, thereby implying a definite period of sub-aerial denudation and consequently a break of greater or lesser extent between the Carboniferous and the Magnesian Limestone Third, although it is not quite clear what he meant to imply by the term "drift sand," it is possible that he looked upon the beds as being in the nature of dune sands Finally, he placed the whole of his lower red sandstone group as the equivalent of the Rothegende

Following closely upon Sedgwick's work, a paper was published by the local geologist, William Hutton.⁴ In this paper Hutton divided the lower red sandstone group of Sedgwick into two parts, the upper part being generally an incoherent sand of light buff colour, and the lower a more compact, micaceous sandstone of variegated red, yellow and purple colour He says We shall designate the upper bed as the Yellow Sand, from its prevailing character, and the lower as the Red Sandstone, but without in the least wishing them to be considered in any other light than as different members of the same formation'

Hutton further attempted to prove that the Red Sandstone was unconformable with the Coal Measures by showing that the depth of the Hutton Scar below the Red Sandstone varied considerably at different places along its outcrop He thus concluded that the Yellow Sand and the Red Sandstone, being unconformable with the Coal Measures, were rightly included in the New Red Sandstone series, and should be assigned to the subdivision of the Rothegende, as Sedgwick had suggested

In 1857 another local geologist, Richard Howse, attacked, on palaeontological evidence, the prevailing idea of the New Red Sandstone age of the Red Sandstone, and proposed that it should be included in the Coal Measures⁵ In support of this age he gives the following list of fossils which he collected from the Red Sandstone

- Pinites Brandlingi*
- Trigonocarpon Noggerathi*
- Sigillaria reniformis*

Lepidodendron Spec indet

Calamites appr ximatus

Calamites inequalis

Spine cf Gyracanthus formosus

While from a shale intimately connected with the sandstone he obtained *Neuropterus gigantea* *Sphenopteris latifolia* and *Cyclopterus d latata*

With regard to the Yellow Sands he believed that the variable thickness of the beds within short distances proved them to be unconformable with the overlying Magnesian Limestone series and consequently proposed that they should be considered as the uppermost member of the Carboniferous

In a later work published in 1930⁴ Howse modified this opinion to the extent of including the Yellow Sands in the Permian and suggesting that they might be the equivalent of the German Weissliegende

Between the publication of Howse's two papers very little work was done in this area on the Yellow Sands and the next paper of importance is that published by Lebour in 1902. Dealing with the question of the apparent conformity of the Yellow Sands and the underlying Red Sandstone Lebour makes the following observations

(a) That there is usually a discordance in the dip between the two series and that parallel stratification is rare and only accidental

(b) That the Red Sandstones represent various horizons in the Coal Measures and are in fact only the stained edges of the Coal Measure sandstones

(c) That the majority of the faults which affect the Coal Measures dislocate the Red Sandstone but do not affect the Yellow Sands

As a result of these observations Lebour concluded that an unconformity must exist between the Yellow Sands and the underlying rocks

With regard to the conditions of deposition of the Yellow Sands and Marl Slate Lebour suggests that the former were accumulated as dunes on the shores of the Magnesian Limestone sea, filling up hollows in the eroded surface of the Coal Measures while the Marl Slate was a

lagoonal deposit of calcareous and magnesian muds the material of which the Yellow Sands are formed he considered to have been chiefly derived from the Carboniferous sandstones

Woolacott¹⁰ supported in general the conclusions reached by Lebour, but added the opinion that the material of the Yellow Sands had been derived from an area lying to the north and west in which some metamorphic rocks were exposed (e.g. Central Scotland)

The general consensus of opinion amongst previous writers may therefore be taken to be that the Yellow Sands are unconformable with the underlying red sandstones, and should be included with the Magnesian Limestone and Marl Slate in the Permian or Permo-Trias. The position of the Marl Slate is much clearer than that of the Yellow Sands, principally by reason of its fossil content, and its obvious general conformity with the Magnesian Limestone. It was early referred to as the lowest member of the New Red Sandstone series in which it was placed by Sedgwick, who correlated it on lithological and palaeontological evidence with the copper-slate (i.e. the Kupferschiefer) of Thuringia.¹⁰

III Field Relationships

(a) General Distribution

(i) Along the outcrop

The Yellow Sands may be traced along the base of the escarpment of the Magnesian Limestone where they form a strip of gently sloping ground from South Shields in the extreme north-east of the County of Durham, to the neighbourhood of Ferryhill in the south (see accompanying sketch map Plate I). The outcrop is not entirely continuous because of the greatly varying thickness of the sands. In places, however, the Sands are undoubtedly present under the Drift, although not visible at the surface (see page 423).

Occasionally, the Yellow Sands are absent and the Marl Slate rests directly on the Coal Measures, as at Newbottle, where the Magnesian Limestone is mapped by the Geological Survey as resting on Coal Measure sand-

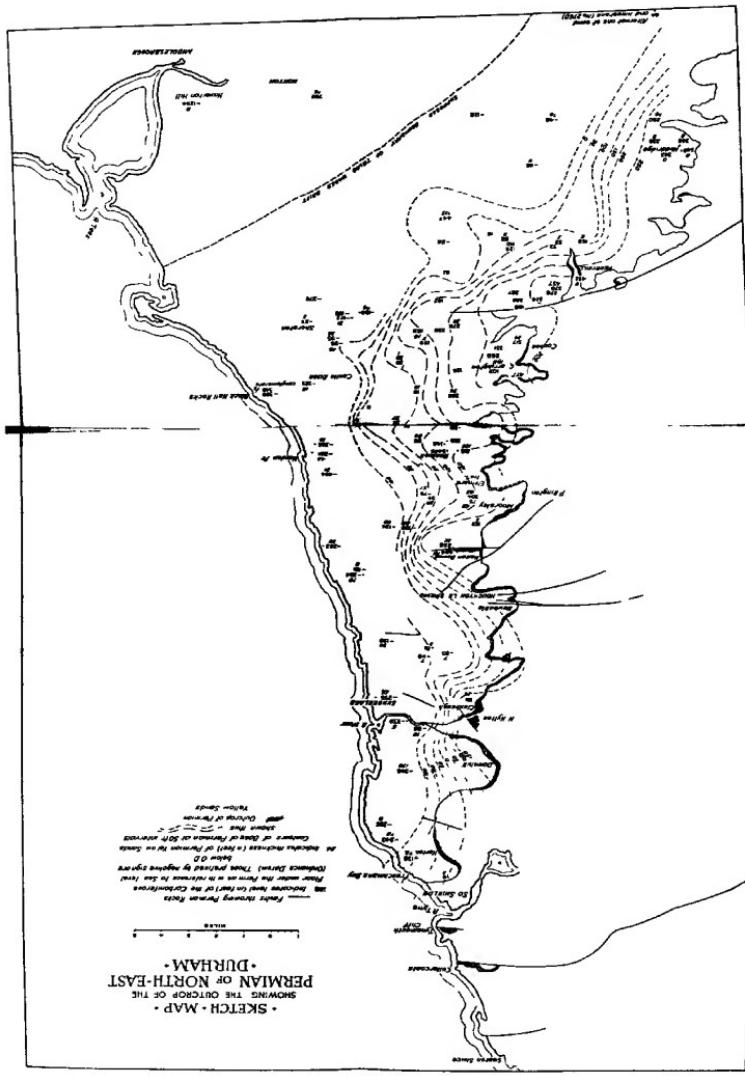


PLATE I.

stones. It seems probable that where the Sands are now entirely absent they have been removed by circulating waters subsequent to the deposition of the Magnesian Limestone. The Yellow Sands are almost always a water-bearing horizon, and in many cases are actually "quick-sands" through which there is considerable difficulty in sinking pit-shafts. Further, Lebour has pointed out¹¹ that where springs issue from the Yellow Sands at the foot of the escarpment "cones of dejection" frequently occur, the cones being made up of sand brought from within the beds. This, he believed, would considerably alter the distribution of the sand within the beds, and would account for the local inequalities in the base of the overlying Marl Slate or Magnesian Limestone. There seems every reason to suppose that such action, long continued, would entirely remove large portions of the unconsolidated Sands, and in addition might be the indirect cause of much of the brecciation in the Magnesian Limestone by withdrawing support from these overlying beds and causing their collapse.

Isolated patches of the Sands occur in the extreme south-east of Northumberland at Collywell Bay, Cullercoats Bay and Tynemouth Cliff. In the outcrops at Collywell Bay and Cullercoats Bay the Sands have been preserved by the agency of a series of parallel faults running approximately E. W., which have dropped them into a protected position amongst the Coal Measure sandstones. The Tynemouth Cliff exposure is more probably a simple outlier due to denudation. A fault affecting the Coal Measures is present on the south side, but there is no evidence to show that it affected the Permian rocks.

South-west of Ferryhill there are few outcrops, while the records of borings seem to show that the Sands become thinner, and eventually die out.

(ii) Distribution below the Magnesian Limestone.

The general opinion expressed by earlier writers, including Lebour, is that the Yellow Sands were deposited in depressions in the Coal Measure floor, and with a view to testing this hypothesis an attempt has been made to

reconstruct the topography of the area during Permo-Carboniferous times. This has been made possible by the information contained in the volumes of "Borings and Sinkings" published by the North of England Institute of Mining Engineers.

The spot-levels of the surface of the Coal Measures were plotted on a one-inch to the mile map of the area and, after the necessary averaging process, contours were drawn at intervals of fifty feet. These contours are shown on the map, Plate I, while the thicknesses of the Sands, in places where they are recorded, are shown by the figures in italics. Where the reports are such as to leave no doubt that the Sands are absent, this is indicated on the map by a "o".

It will be seen from the map that the Coal Measure surface slopes very gently to the south-east over the greater part of the area, with a slightly steeper slope (about 1 in 20) along a strip about one mile wide which runs in a south-westerly direction parallel to, but a little west of, the line Horden Point—Castle Eden. There is a spur of higher ground centred round the present Quarrington Hill, the axis of the spur running N.W.—S.E. South and south-east of this, borings which penetrate through the Permian into the Coal Measures are few, but they show that the general dip to the S.E. is continued. In the northern area the dip of the Coal Measure surface seems to become more easterly, but records of deep borings are insufficient to make any more definite statement.

With regard to the distribution of the Yellow Sands, there seems to be no very close connection between their occurrence and the Coal Measure surface when this is contoured at fifty-foot intervals. So far as can be ascertained, the maximum development is in the central part of Durham around the two areas of Hetton Downs and Haswell, and again on the coast between Horden Point and Ryhope. In the areas lying to the north and to the south of this central area the Sands are usually under fifty feet thick. Southwards, they undoubtedly die out altogether against the ridge of Lower Carboniferous rocks

which run in an E-W direction from a point a little south of the mouth of the River Tees across to Barnard Castle whose position is just west of the SW corner of the map.

The sporadic nature of the occurrence of the Yellow Sands is well exemplified in the Hetton Downs district. At Hetton Downs Colliery their thickness is 111 feet while one mile to the south west at Moorsley the thickness is only five feet and one mile south of Moorsley at Elmore Colliery (Pittington) the thickness is 63 feet.

(b) Description of Principal Outcrops

In the following description the outcrops are followed systematically from north to south of the area under consideration and a short account is given of each exposure or group of exposures.

(i) Collywell Bay—Seaton Sluice

The section at this locality is shown in fig. 1 from which it will be seen that the Yellow Sands occur in a small patch in the upper portion of the cliff where they

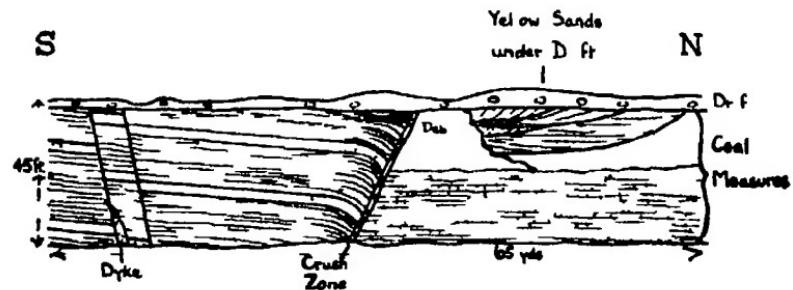


Fig. 1

occupy a depression in the surface of the underlying Coal Measure shales. The relationships of the various beds in this section are very considerably obscured by the wash-down of debris from the Drift capping of the cliff, but so far as they can be determined the structure points to the presence of a reversed fault in the position shown in the figure. Its position can only be determined with approxi-

mate accuracy by the existence of a crush-breccia composed of fragments of Coal Measure sandstone set in a greyish-white soft matrix which seems to be largely made up of crushed sandstone and shale. On the north side of this fault the Coal Measures are represented by beds of shaly-sandstone and on the south side by sandy shales with beds of sandstone.

The Yellow Sands here consist of beds of very friable sandstone of which the prevailing colour is a brownish yellow. In detail the beds are seen to be made up of alternate layers of very thin coarse-grained bands of dark brown colour and of thicker bands composed of a mixture of coarse rounded grains and fine, angular grains the mixed bands being yellow in colour. The whole shows a high degree of cross-bedding of an aeolian type.

(ii) Cullercoats Bay

The Permian outcrops here at the southern end of the small bay above which stands the village of Cullercoats, and the three divisions of the system namely the Yellow Sands, the Marl Slate and the lower part of the Magnesian Limestone are all represented the whole being much disturbed by the big fault known as the Ninety Fathom Dyke, which here lies towards the NNE and brings the Permian beds down against the Coal Measures lying to the south of the fault.

The Permian beds are folded into a small anticline and syncline, pitching in an approximately easterly direction. The Yellow Sands have been exposed by denudation and now appear lying to the north and south of the synclinal fold of the Magnesian Limestone and Marl Slate, abutting against the Ninety Fathom Dyke on the south.

The bedding of the Sands is obscured by the disturbed condition of the outcrop the crushing against the fault plane having resulted in the formation of a great number of minor faults in the body of the Sands. Frequently these minor faults are marked by veins of calcite which on weathering, stand out as ridges above the softer intermediate sand. As a whole, however, the outcrop is fairly well cemented by calcite, and consequently resists erosion.

much better than the more incoherent beds of the southern area to be described later

(iii) *Lynemouth Cliff*

The sequence exposed in the cliff below Lynemouth Priory is as follows

Brecciated Middle Limestone	10-20 feet
Bedded Lower Limestone	11 18 feet
Marl Slate	3 feet
Yellow Sands	5 25 feet

At this locality the unconformable junction of the Yellow Sands with the red sandstones and shales of the Coal Measures is well seen near the base of the cliff. Immediately above this junction on the east face of the cliff there is a bed of sand about one foot thick, which contains a small percentage (0.05 per cent) of quartz pebbles with diameters between 2 mm and 4 mm. Similar occurrences have been noted at other places usually in borings. They seem to be the nearest approach to a basal conglomerate ever present in the Permian in the north-eastern area.

In colour the Sands are a dark brownish-yellow and the texture appears to be rather finer than that of the more southerly outcrops in Durham and while there is a considerable amount of false-bedding it is not so extreme as in the southerly exposures.

While the Sands occur here in their usual place beneath the Marl Slate there are also intercalations of sand of the same type between the various beds of the Lower Limestone again below the Marl Slate on the north end of the cliff, a band of magnesian limestone six inches thick occurs in the Yellow Sands. Such intercalations have also been noted in borings in Durham, the inference being that sandy conditions were still prevailing over part of the area while the Marl Slate and Lower Limestone were being deposited.

On the north side of the cliff there are bands in the Yellow Sands containing segregations of magnetite grains, together with some ilmenite (see p. 424).

Immediately under the Marl Slate the Yellow Sands are firmly cemented by calcite for the depth of about one

foot, so that they actually form a band of calcareous sand-stone. In the other parts of the exposure the Sands are usually quite incoherent, with just occasional irregular hard bands similar to the above.

South of the River Tyne, in the County of Durham, the main outcrop of the Permian begins at the southern end of the South Beach at South Shields, and thence extends continuously along the coast to the mouth of the River Tees, while inland its boundary runs approximately N. S. as far as Quarrington Hill, and from there strikes in a south-westerly direction towards the county boundary. The general dip is E. by S. at a very low angle, consequently most of the exposures of the Yellow Sands now to be described occur on the westerly margin of the outcrop.

(iv) *Frenchman's Bay—South Shields.*

At times when the beach sand has been either blown or washed away, a small outcrop of the Yellow Sands can be seen at the north end of the Bay, near the base of the cliff and about twenty yards north-east of the foot of the steps. When examined by the author it was only exposed to the extent of about three feet in length and six inches in width, and proved to be a consolidated sand very similar to the Tynemouth type. An outcrop of the Marl Slate also can be seen on the south side of the Bay at low tide, beneath the Lower Bedded Limestone.

(v) *Harton—South Shields.*

At this locality there is no outcrop, but during drainage operations in the new south extension of the Harton Cemetery the Yellow Sands were exposed in a series of trenches cut through the Drift. The Lower Limestone is present under the Drift near the old boundary wall of the cemetery, but the Yellow Sands extend southward beyond the limestone, and immediately underlie the Drift at a distance of fifty yards from the wall where the drainage trenches were sunk through seventeen feet of the Sands without reaching the Coal Measure surface.

In character the Sands here are in general incoherent but with occasional harder bands with calcite cement. The colour varies greatly from dark brown to pure white in irregular patches and lenticles. There is the usual admixture of coarse and fine grains present.

(vi) *Down Hill and Hylt : Castle West Boldon*

There are exposures of the Yellow Sands in two sand pits in this area. The more northerly one is on Down Hill Farm about half a mile south of West Boldon and the southerly one is on the north side of the road from Lsworth Station to Sunderland near Hylton Castle. The limestone is present above the Sands in both cases.

The character of the Sands in both pits is fairly typical of the Durham outcrops the colour is light yellow with occasional darker bands and also lenticles of white, coarse-grained sand. The usual alternations occur of thin layers and lenticles of large rounded grains and thicker layers of similar coarse, rounded grains in a matrix of finer-grained, angular and sub-angular material. The cementing is irregular as in the other outcrops already described and frequently the calcite has become segregated around a nucleus of sand grains with the result that on weathering, a series of nodules about a quarter of an inch in diameter stand out from the surface of the rock.

Woolacott states that at one part of the Down Hill pit the grains are coated with manganese dioxide but this part is now covered by debris and the statement cannot be verified.

(vii) *North Hylton and Claxheugh*

This, the largest exposure of Yellow Sands in the county, extends for nearly 600 yards along either bank of the River Wear west of Sunderland. The total thickness from the junction with the Coal Measures on the north bank to the junction with the Marl Slate on the south bank of the river is about 100 feet. At the eastern end of the exposure there is a fault running N W — S E., which causes the Permian beds to abut against the shales and sandstones of the Coal Measures. Accompanying the

fault there is a series of calcite and clay veins in the Yellow Sands, as at Cullercoats. These veins appear to be a characteristic phenomenon wherever the Sands have been disturbed by earth movements.

Contrary to the opinion expressed by Woolacott with reference to the Yellow Sands in general, the cross-bedding in this exposure is much more highly developed in the upper portion than in the lower. In the lower portion, on both sides of the river, the layers are horizontal, and consist of the usual alternations of coarse and mixed laminæ. Frequently the coarser grains are arranged in lenses up to eight inches in length and three-quarters of an inch in width. Towards the western end of the exposure the deposit loses its layered character, and becomes simply a mass of friable, fine-grained sand.

The colour varies from greyish-white to dark brownish-yellow, while the cementing is similar to that of the exposures on Down Hill.

On the south (Claxheugh) side the base of the Yellow Sands is not seen, but its upper junction with the Marl Slate is well shown. There is a very thin but persistent band of yellow clay, one inch in thickness, between the two beds. The Marl Slate is about two feet thick, and lies horizontally on the Sands; it is sandy at the base, and becomes more calcareous towards the top. Lying conformably on the Marl Slate, but separated from it by a band of soft "marl" one inch thick, is the Lower Bedded Limestone, and above this comes the Middle Unbedded Fossiliferous Limestone of Woolacott.

On the north side of the river the junction with the Coal Measures may be seen, but the higher beds of the Permian are absent. At the western end the Sands are seen to lie unconformably on a surface of stained, massive, fine-grained sandstone belonging to the Coal Measures. This floor dips gently to the east from Baron's Quay Lane until it is lost beneath the river shore. A section of the river bank thus appears as shown in fig. 2.

(viii) Offerton, Penshaw Hill, and Flinton Hill

Small exposures occur along the base of the escarp-

ment of the Magnesian Limestone at these places. The Sands are usually incoherent, and of the normal type.

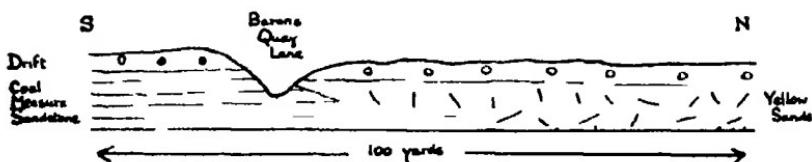


Fig. 2

(ix) *Houghton-le-Spring.*

About ten feet of the top of the Sands may be seen in an old quarry, near the colliery, at Houghton-le-Spring. They are fine in texture, massive, and compact, though quite friable.

(x) *Helton Downs.*

A large sand and limestone quarry (High Downs Quarry) shows an excellent section of the Yellow Sands at this locality. In the quarry the Sands reach a thickness of forty feet, but the base is not seen. The lowest visible portions show the typical aeolian cross-bedding noted farther north at Down Hill and Claxheugh; that is, the upper layers curve round so as to become tangential to the planed-off surfaces of the lower layers. The upper portion is massive, and the colour varies from pure white to dark brown. At the eastern end of the pit the upper massive portion is seen lying on an irregular surface of the false-bedded lower part as shown in fig. 3.

The cementing is, as usual, confined to irregular bands and spherical nodules, the latter being particularly well developed.

(xi) *Moorsley, Pittington, and Elemore Hall.*

Small exposures may be seen on the slopes to the north of High Moorsley village, in a quarry half a mile north-east of Pittington, and in the grounds of Elemore Hall (this latter outcrop is not shown on the one-inch map). No peculiar features are noticeable in any of these. At the

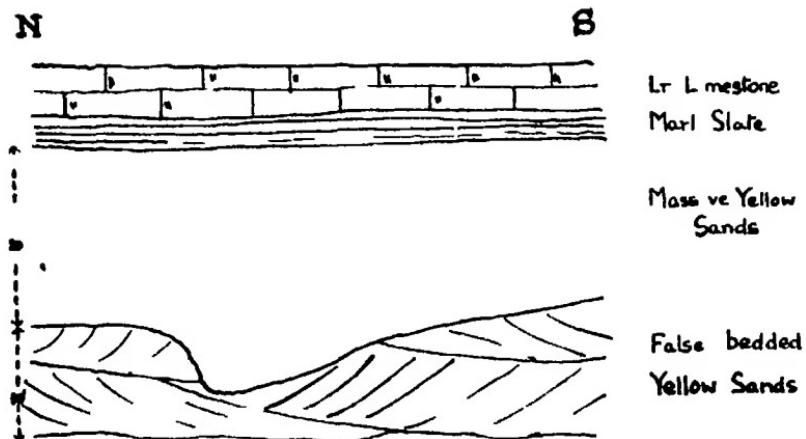


Fig 3

Moorsley sand pit a hard, cemented band underlies the Marl Slate, the coarse layers forming planes of weakness along which the sandstone splits easily

(xii) Coxhoe

The sands are exposed in a limestone quarry in the hillside, east of Coxhoe village. They are dark brown in colour and usually incoherent, and in general very similar to the outcrops already described. The total thickness exposed is ten feet but the base is not seen

(xiii) Ferryhill Railway Cutting

This exposure occurs in the railway cutting at the north end of Ferryhill station, on the L N E R main line. The bedding is again of the aeolian type, but the layers of coarse grains reach a much greater thickness here than in any of the other exposures, attaining at the southern end a thickness of three to four feet. These coarse bands are very firmly cemented with calcite, and run through the softer and finer portions in various directions, often truncating each other (see fig 4)

(c) Summary of Field Evidence

It may be desirable here to sum up the evidence presented by work in the field

It is found that the Yellow Sands occur along the base of the Magnesian Limestone escarpment, immediately under the Marl Slate in most cases throughout the greater part of the area under consideration. Evidence yielded by borings proves the Sands to disappear completely in

N

S

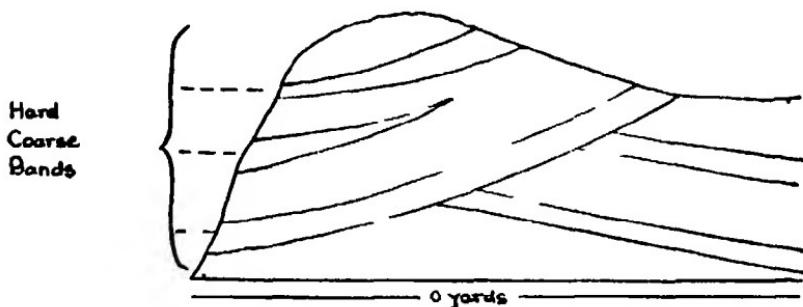


Fig. 4

the south-east of the county. In the south there is a ridge of Lower Carboniferous rocks running in an E-W direction across the county beneath the Permian and against this ridge the Yellow Sands die out, and are thus entirely cut off from the Lower Permian of Yorkshire.

The colour in outcrops is usually light yellow, but there is a considerable local variation from a dark yellowish-brown to a greyish-white. In this feature it presents a striking contrast to the red colour of the Permian sandstones on the west side of the Pennines as typified by the Penrith Sandstone of the Eden Valley.

It is very irregularly cemented by calcite, in some places being a compact calcareous sandstone and in others quite incoherent, with little trace of cementing material. Immediately under the Marl Slate it is usually well cemented due to the leaching down of calcareous solutions from the overlying limestones while in the neighbourhood of faults it is veined with calcite or occasionally with a stiff brown clay.

One of the most noticeable phenomena is the prevalence of cross-bedding of a type usually associated with wind-

action, and such as may be seen in partially dissected sand-dunes in coastal areas notably on the Northumbrian coast at Budle Bay and especially well at Eskmeals on the Westmorland coast. The individual layers, as already noted above, consist of coarse, well-rounded grains either in thin regular bands or in lenses, and of much thicker layers of material made up of the large grains intermixed with a large proportion of finer angular and sub-angular grains. The author has seen an exactly similar phenomenon in the Navajo Sandstone of (?) Jurassic Age in eastern Utah, U.S.A. This sandstone is believed by Reeside to be probably a wind-blown deposit,¹⁴ and there seems little doubt that this particular type of association of coarse and fine grains is an important criterion in distinguishing such deposits.

IV Petrology

(a) Mechanical Analysis

The methods used in making these analyses were based on the work of Professor P. G. H. Boswell¹⁵ and Dr H. A. Baker.¹⁶

In the case of the cemented or partly cemented types, it was found necessary to carry out preliminary treatment with dilute hydrochloric acid (1 in 10), in order to remove the calcite cement. The amount of cementing material was estimated in these samples and a representative series of results is given below in Table I.

TABUL I

Sample	Cementing material etc	Feld Description
A ₁	17.30%	Consolidated sandstone
A ₂	1.67	Slightly cemented
A ₃	4.10	Slightly cemented
A ₄	8.58	Incoherent, but with nodules cemented by calcite
B ₁	1.41	Incoherent
B ₃	1.88	Almost incoherent
B ₅	1.22	Incoherent
B ₇	1.02	Very slightly cemented
B ₉	5.92	Partially consolidated

- A₁ Lynemouth Cliff, south end, base of Yellow Sands
 at junction with Coal Measure sandstone
- A₂ Lynemouth Cliff, south end, 7 feet above A₁
- A₃ Lynemouth Cliff 10 yards north of A₁, near base
- A₄ Lynemouth Cliff, 10 yards north of A₁, 7 feet
 above A₃
- B₁ Hylton Castle sand-pit south end, at floor of pit
- B₃ Hylton Castle sand-pit, south end, above B₁, and
 about 5 feet from top of sand
- B₅ Hylton Castle sand-pit, from middle layers, about
 15 feet north of B₁
- B₇ Hylton Castle sand-pit from base about 30 feet
 north of B₁
- B₉ Hylton Castle sand-pit near upper surface of sand,
 about 40 feet north of B₁

It should be noted that the percentages given in the above table are likely to be slightly high, since part of the grain-coating and some soluble minerals pass into solution in the acid.

Owing to the presence of an appreciable concentration of electrolytes in the local water-supply, it was found necessary first to separate the clay grade by the method of settling in distilled water, in order to avoid the rapid flocculation of the clay particles which occurred in the elutriators which were worked off the ordinary water-supply. After the separation of the clay grade the usual elutriation procedure was followed, and the material separated into the following grades:

Clay	Less than 0.01 mm diam
Fine silt	0.01 — 0.05 "
Coarse silt	0.05 — 0.10 "
Fine sand	{ 0.10 — 0.15 " 0.15 — 0.20 " 0.20 — 0.25 "
Medium sand (in part)	{ 0.25 — 0.30 " 0.30 — 0.35 "

In the Yellow Sands there is generally a considerable amount of coarse material which is outside the limits of

satisfactory elutriation, that is, of greater diameter than about 0.3 mm. In order to obtain complete grading curves for the samples analysed, it became necessary therefore to utilize some method of grading other than elutriation but which would give results comparable with elutriation results as far as possible.

Two alternatives present themselves, namely, either sieving or direct measurement under the microscope. The ordinary disadvantages in the use of sieving have been treated extensively by various authors, notably Ken and Haines,¹⁷ and need not be detailed here. There is, however, a special disadvantage which applies in this case. In passing through the meshes of the sieve the grains tend to turn so that their minor and intermediate axes lie in a horizontal plane, while in elutriation the grains present their greatest surface area to the upward current of water, that is, the major and intermediate axes lie in a horizontal plane. It is obvious then that the completion of a mechanical analysis in this way by sieving immediately introduces the possibility of a divergence of results in the two parts of the curve plotted from the data obtained by the two methods. On the other hand, while being measured under the microscope the grains will tend to lie in the same manner as in elutriation, especially if they are immersed in a mounting liquid. This method was therefore adopted, and Clove Oil was chosen as the most suitable immersion medium.

In practice the diameters of several hundred grains from the elutriator residue are measured by means of an eyepiece micrometer, and the grains are classified into groups with intervals of 0.1 mm. diameter, thus:

Medium sand (in part)	{	0.3	—	0.4	mm diam
		0.4	—	0.5	" "
	|	0.5	—	0.6	" "
	|	0.6	—	0.7	" "
Coarse sand	|	0.7	—	0.8	" "
	|	0.8	—	0.9	" "
	|	0.9	—	1.0	" "
Very coarse sand. Above 1.0 mm					"

The number of grains in each group is counted, and the proportion by weight and subsequently the percentage of that group in the total sample is calculated.

This method provides a flowing curve in continuation of the portion obtained by elutriation, and seems to be sufficiently accurate provided that

- (1) It is applied to large rounded grains, as in the case of the Yellow Sands.
- (2) The intervals of grade size are of the order of 0.1 mm or more.
- (3) A large number of grains is measured.

Results of Mechanical Analysis

The numerical results obtained are given in Table II. Grading curves drawn according to the method adopted by Baker¹⁸ are peculiar in showing more than one maximum in the case of analyses of the Yellow Sands. The curves are found usually to be made up of two distinct portions, the lower part, lying below the line representing a diameter of 0.25 mm having a well-defined maximum, indicating a high degree of grading between the limits of 0.05 mm and 0.15 mm diameter. The upper part is almost invariably irregular, with occasionally a poorly defined maximum indicating incipient grading. Examples of this type of curve are given in figs. 5, 6, and 7.

A study of these curves will immediately demonstrate very clearly the phenomenon which has already been noted in the field, namely, that two main grades prevail in most localities, corresponding with the maxima in the curves. These grades are the Fine Sand and the Coarse Sand. Two possible explanations of this double maximum suggest themselves. First, it may be that the material making up the deposit has been drawn from two localities in which the original quartz grains were of different size. Second, the double mode may be due to the differential action of the agent of transportation in carrying the finer material in suspension, while rolling the coarser material. Coupled with these explanations is the necessity for postulating the fairly close proximity of the parent rocks, especially if the transporting agent be wind, since wind

TABLE F

CLAY	SILICATE	QUARTZ	SILICATE SILT	Fine Sand			Medium Sand			Coarse Sand			Very Coarse Sand			
				0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.70	0.80	
A.2	4.25	1.01	2.3	4.3	9.98									13.27		
A.3	4.12	0.96	0.09	4.9	4.45									13.91		
A.4	3.93	1.34	11.34	59.1*										6.81		
A.5	1.62	0.87	0.83	21.27										60.43		
A.6	4.61	1.26	20.57	64.92										3.31		
B1	5.17	2.12	22.33	47.05										22.6		
B2	1.51	3.84	12.02	34.64	-37.84	41.64	-	12.15	-17.16	11.06	6.2	3.96	4.2	1.31	0.79	
B3	5.81	1.46	20.91	24.36	9.03	6.27	6.20	4.27	-2.07	—	3.49	4.14	4.23	2.83	1.41	0.70
B4	2.98	* 37	17.85	-32.60	—	6.50	5.84	-4.00	—	8.49	5.66	4.18	2.6	1.10	1.52	1.24
B5	4.18	1.70	11.27	14.89	2.73	3.67	3.69	2.23	0.4	6.48	8.10	9.7	8.10	7.02	0.94	7.0
B6	3.60	2.57	13.14	-21.44	—	3.33	7.49	-6.25	—	17.21	8.17	4.44	21	2.95	4.13	1.39
B11	5.50	3.16	13.75	2.78	6.60	4.0	4.9	4.88	-4.96	—	6.08	9	4.64	4.16	3.0	0.80
B7	4.80	4.77	20.39	10.37	7.97	9.60	13.35	10.00	0.7	—	1.73	—	3.0	1.63	0.87	0.63
H4	9.46	2.54	30.04	10.89	4.09	6.09	13.00	—	13.08	-4.0	10.16	8.02	3.07	1.0	0.40	0.3

LOCALITIES

A2 Tynemouth Cliff South end, feet above junction with Coal Measure Sandstone

A3 Do 10 yards North of A2 near base

A4 " feet above A3

A5 Do 25 yards North of A4 near base

A6 Do 7 feet above A5

B1 Hylton Castle Sand pit South end of pit near floor

B2 Do Middle portion above B1

B3 Do Upper portion ^a feet from upper surface above B1

B4 Do 16 feet North of B3 Upper portion

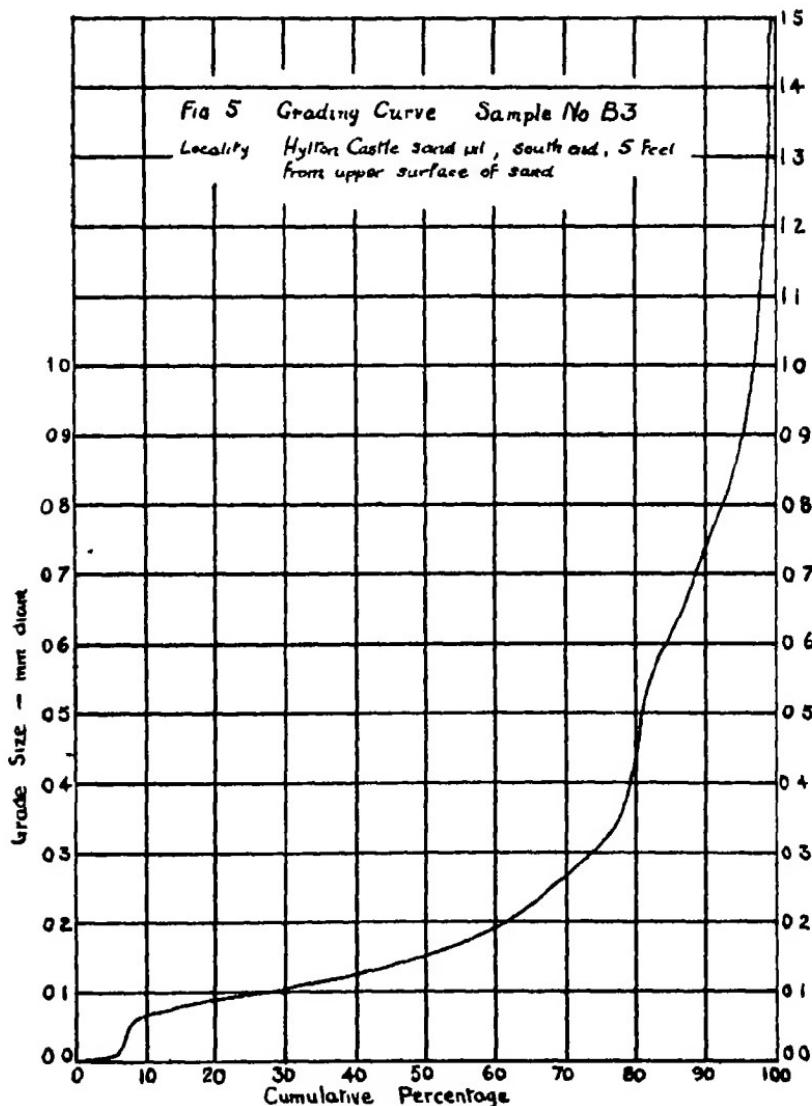
B5 Do Middle portion

B6 Do Near floor of pit

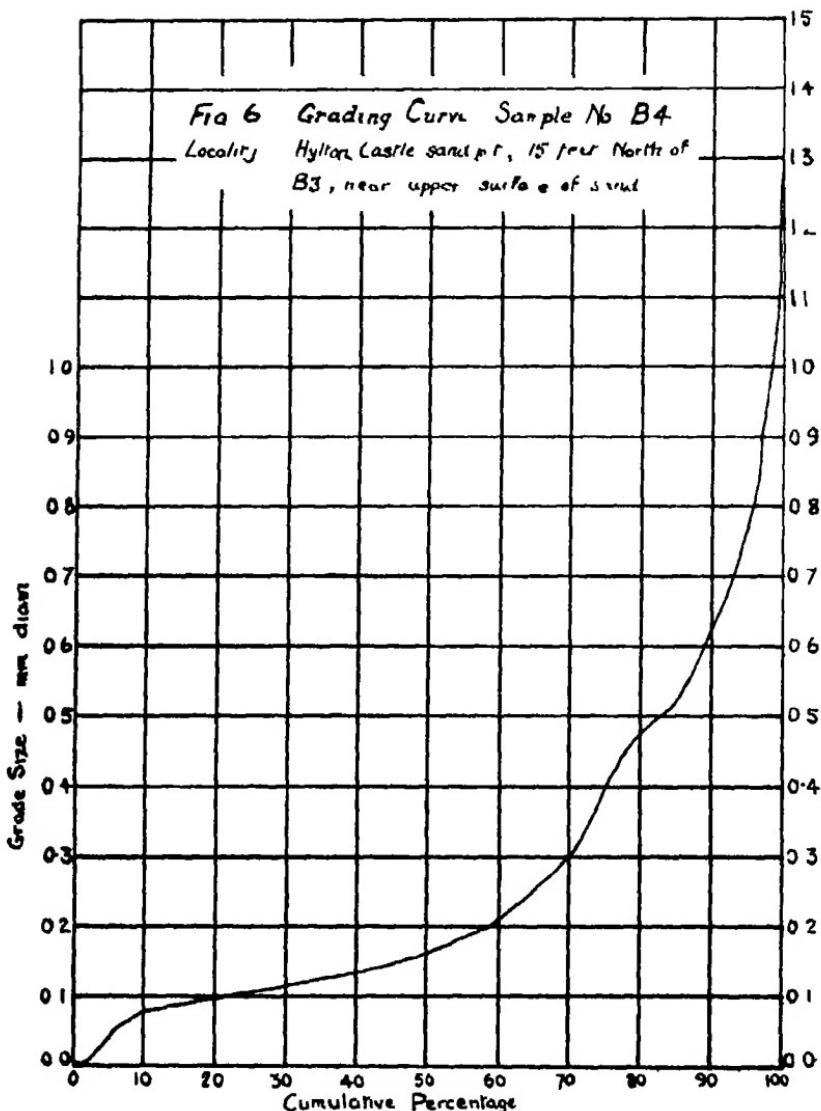
H2 North bank of River Wear opposite Claxthorugh 10 yards from eastern end of exposure

Do do

H4 160 yards West of H2

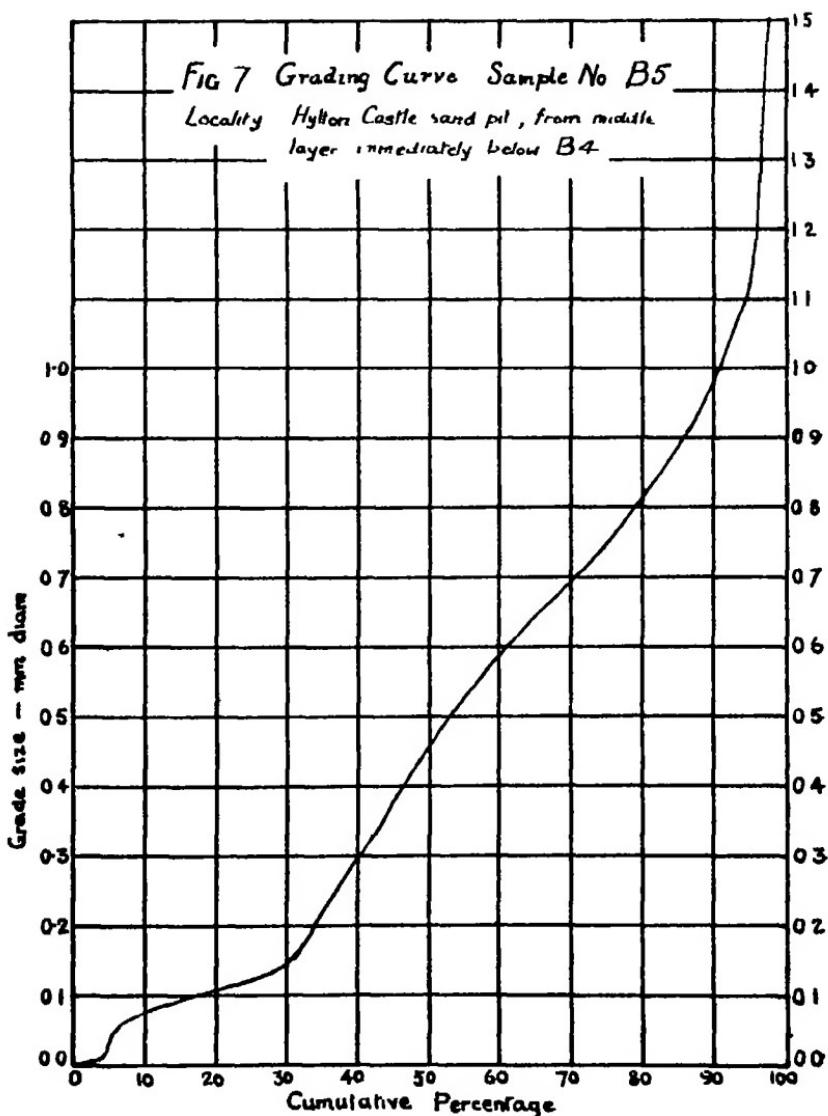


causes rapid grading of detrital material. Of the two possibilities it is probable that the second has the greater effect, although the petrological evidence which will be considered later shows that the first cannot be entirely ruled



out, and indeed it is highly probable that both factors have contributed in the production of this type of sand.

Mention of this double mode is, so far as I have been able to determine, made only by one other investigator, J. A. Udden, who makes the following statement:¹⁹



" When a transporting medium is supplied with sufficiently heterogeneous material it will tend to carry and to deposit more of two certain sizes of material than of any other. The principal deposit it makes will

consist of materials it can momentarily lift. With this it will leave an excess of another considerably coarser ingredient which it can roll, smaller in quantity. This makes what we may call a secondary maximum. For water deposits the secondary maximum will consist of elements having a diameter about sixteen times the diameter of the elements in the chief ingredient. For wind deposits the secondary maximum will consist of elements having a diameter about eight times that of the elements in the chief ingredient."

Udden's experiments were carried out on modern, unconsolidated sands and dusts, and it is interesting to find a similar secondary maximum in the case of these Permian deposits. An examination of the curves given in figs 5, 6, and 7 shows that the diameter of the grains in this secondary maximum is from six to eight times that of the grains in the chief ingredient. Thus we get corroborative evidence that the Yellow Sands are of aeolian origin. It is certain that the curves do not resemble any one of Baker's curves of typical aqueous sediments.

(b) Mineralogical Analysis

The usual method of separation of the heavy minerals by means of bromoform of SG = 2.86 was followed in this investigation. It was seldom found necessary to use hydrochloric acid to clean the grains before separating.

In some cases the percentage of heavy minerals in each grade was determined. This percentage shows the usual decrease with increasing grade size, but if the grade percentage of heavy minerals be converted to percentage of the total sample, it is found to be greatest in the Coarse Silt grade. A typical analysis of this type is given in Table III.

TABLE III

	<i>Grade mm diam</i>		<i>Per cent of Grade</i>	<i>Per cent of total sample</i>
Silt	0.01	—	0.05	0.007
Coarse silt	0.05	—	0.10	0.057
Fine sand	0.10	—	0.25	0.037
Medium sand	0.25	—	0.50	0.018
Coarse sand	Above		0.50	nil

The variation in the total percentage of heavy minerals in each exposure along the outcrop is more important for the purposes of this work. This variation is shown in Table IV. The results are arranged in order from north to south along the outcrop.

TABLE IV

<i>Locality</i>	<i>Sample No</i>	<i>Per cent of Heavy Materials</i>
Collywell Bay	F2	0.27
Tynemouth Cliff	E5	0.39
Harton	L1	0.25
Hylton Castle sand pit	B9 upper portion	0.39
" "	B5 middle	0.19
" "	B11 "	0.24
" "	B1 near floor	0.12
" "	B7 , ,	0.08
North Hylton (Eastern end)	H2	0.32
" (150 yds W of H2)	H4	0.27
Hetton Downs	N3	0.05
Elemore Hall	D	0.12
Ferryhill	G2	0.12

An examination of the percentages shown in Table IV indicates first, that there may be a considerable variation in the amount of heavy minerals in one exposure, and second, that there is no very definite gradation in amount when passing along the outcrop. Taking the Hylton Castle exposure, samples B1 and B7 are taken from near the floor of the pit, B5 and B11 are from the middle, and B9 is from near the top, and thus there appears to be an increase upward of the heavy minerals from about 0.08 per cent to 0.39 per cent, but in fact these positions do not, owing to the extreme false-bedding of the exposure, represent true stratigraphic horizons. This variation in the individual exposures makes it difficult to estimate the variation in passing along the outcrop from north to south, especially as many of the exposures are small and their junctions are unseen, thus making any weighting and

averaging of results impossible. However, there does appear to be a tendency to a decrease in the amount of heavy minerals southward along the outcrop.

Turning now to the types of minerals present in the Yellow Sands, the total number is found to be only eighteen including quartz and the felspars. They are as follows:

<i>Cubic</i>	<i>Tetragonal</i>
Garnet	Anatase
Magnetite	Rutile
	Zircon
<i>Hexagonal</i>	<i>Trigonal</i>
Apatite	Hæmatite
	Quartz
	Tourmaline
<i>Orthorhombic</i>	<i>Monoclinic</i>
Staurolite	Biotite
	Muscovite
	Orthoclase
	Pidote
<i>Triclinic</i>	<i>Amorphous</i>
Microcline	Limonite
Plagioclase	Leucoxene

The distribution of the heavy minerals in a number of exposures from north to south is shown in Table V, while Table VI is a Persistence Diagram of all the minerals. From these two tables it will be seen that there is little variation either in number of species or in the amounts of individual species of minerals in traversing the area from north to south. The only mineral showing a tendency to vary is garnet, which appears to decrease in amount southwards, of the others, anatase occurs in two exposures (Tynemouth Cliff and Harton), apatite in three (Tynemouth Cliff, Harton, and Ferryhill), and staurolite in three (Collywell Bay, North Hylton, and Hetton Downs). Most of the other minerals occur in every exposure.

TABLE V
DISTRIBUTION OF HEAVY MINERALS

Sample No	I 2	E5	L1	N3	D	G2
Minerals						
Anatase	—	1	1	—	—	—
Apophite	—	3	3	—	—	—
Epidote	2	—	—	1	—	—
Garnet	8	6	6	7	5	2
Leucoxene	—	+	+	+	—	—
Limonite	+	+	+	+	+	+
Muscovite	2	2	2	—	—	2
Rutile	5	2	4	4	4	5
Tourmaline	5	4	4	5	—	3
Zircon	6	5	5	5	3	6
Black Iron Ores*	+	+	+	+	—	+

Numbers indicate relative amounts (Milner's Convention)

+ Indicates mineral present but amount not estimated

* Usually Ilmenite in E5 much Magnetite in octahedra

Localities—North to South

I 2—Collywell Bay

E5—Tynemouth Cliff

L1—Harton

N3—Hetton Downs

D—Elemore Hall

G2—Ferryhill

TABLE VI.
MINERAL PERSISTENCE DIAGRAM.

Sample No.	F2	E5	L1	B	H2	N3	D	G2
Minerals.								
Anatase		+	+					
Apatite	+		+					+
Biotite					+			
Epidote	+				+	+		
Garnet	+	+	+	+	+	+	+	+
Haematite	+	+	+	+				
Ilmenite	+	+	+	+	+	+		+
Leucoxene	+	+	+	?	+	+		
Limonite	+	+	+	+	+	+	+	+
Magnetite	?	+	?	?	+	?		?
Microcline	+	+	+	+	+	+	+	+
Muscovite	+	+	+	+	+			+
Orthoclase	+	+	+	+	+	+	+	+
Plagioclase	+	?	+	+	+	+	+	+
Quartz	+	+	+	+	+	+	+	+
Rutile	+	+	+	+	+	+	+	+
Staurolite	+					+		
Tourmaline	+	+	+	+	+	+		+
Zircon	+	+	+	+	+	+		+

Localities—North to South:

F2—Collywell Bay.
 E5—Tynemouth Cliff.
 L1—Harton.
 B—West Boldon (Hylton Castle).

H2—North Hylton
 N3—Hetton Downs
 D—Elemore Hall.
 G2—Ferryhill.

Details of the characteristics of each mineral are given below

Anatase

Localities Tynemouth Cliff and doubtfully at Harton

In the Tynemouth Cliff exposure anatase occurs in the typical minute tabular crystals square in outline and with bevelled edges that is the forms present are (001) and (111). It is brownish grey in colour with sub-metallic lustre. The refractive index is very high uniaxial negative. In the Harton exposure only one grain was found this was subangular in shape but otherwise its characteristics were the same as those of the Tynemouth specimens.

Apatite

Localities Tynemouth Cliff Harton and Ferryhill

Occurs in small rounded and sub rounded grains often with minute (?) crystalline inclusions. Basal fragments are common but sub rounded prismatic fragments also occur and frequently show traces of basal cleavage, and also longitudinal striations especially those from Ferryhill. Colourless high refractive index low birefringence uniaxial negative.

Biotite

Locality North Hylton

This mineral has only been noted from the above exposure. It occurs in small rounded or irregular flakes, brownish yellow or faintly greenish in colour and contains no inclusions.

Garnet

Occurs in all outcrops

Three distinct types have been noted as follows

- (1) Colourless, usually angular with occasional sub-angular or rounded individuals moderate to strongly developed dodecahedral cleavage medium size sometimes in small fragments
- (2) Brown-pink to clear reddish-brown rounded to sub-angular cleavage strong to moderate, occasionally lacking, large size, i.e. 0.25—0.4 mm diam

- (3) Clear, faint pink; almost invariably rounded; traces of cleavage, never strongly developed, and sometimes entirely lacking; large size; usually have frosted and pitted surface.

Of the three types, the colourless one is the most common and the pink type the most rare, possibly owing to the cleavage in the colourless type leading to a multiplication of individuals.

Hæmatite.

This mineral is occasionally seen in the more northerly outcrops, where it appears as an alteration product of magnetite. Magnetite grains are seen which have a coating of red material which has been identified as hæmatite. In some cases a brownish-red streak can be obtained on white paper with the grains which have undergone complete alteration.

Ilmenite, Limonite, and Leucoxene.

Occur in every exposure.

The ilmenite is usually in small, rounded or irregular black grains. In the Tynemouth Cliff and Collywell Bay outcrops there are a few more regular grains having a crimson sheen in reflected light, and out of which minute crystals of a deep brownish-red mineral, probably rutile, are growing. More commonly, however, the ilmenite has a coating of brown limonite, or is pseudomorphed in a white earthy material, probably leucoxene. Limonite is by far the most common of the iron ore minerals, existing both as grain coating on the quartz and felspar, and as individual grains where it has replaced the ilmenite, or possibly as suggested by Woolacott²⁰ as a replacement product of pyrite. To the ubiquitous presence of limonite is due the prevailing colour of the Yellow Sands at the outcrop.

Magnetite.

Localities: Tynemouth Cliff, North Hylton, and doubtfully in other places.

Occurs in minute octahedra dull or with sub-metallic lustre, magnetic. Usually in much smaller amount than ilmenite. Sometimes has a surface coating of haematite or limonite.

Microcline

Occurs in every outcrop together with the other felspars.

The grains are usually smaller in size than those of the other felspars. Shows typical cross-hatching, especially in thin section (see Plate II, fig. 4). Usually it is only slightly altered and is occasionally quite fresh. Next to orthoclase it is the most abundant of the felspars in the Sands.

Muscovite

Occurs in all localities except Hetton Downs and Flemore Hall.

Occurs in medium-sized, rounded or irregular flakes, sometimes with minute crystalline inclusions, and often having a faint, greenish tinge. It frequently shows undulose extinction.

Orthoclase

Present in all outcrops.

Orthoclase is the most common of the felspars. It occurs in large, rounded grains, usually showing a moderate degree of alteration. No twinning was seen.

Plagioclase

Occurs in all outcrops with the doubtful exception of Tynemouth Cliff, but is the least common of the felspars.

It usually shows a moderate degree of alteration. Its refractive index and extinction angle indicate that it is probably Albite-oligoclase. Multiple twinning is invariably present.

The three felspars together make up from 10 per cent to 20 per cent of the whole of the light crop, but appear to decrease a little in amount towards the south of the area.

Quartz.

The quartz grains vary in size from about 1.5 mm. diam. downwards. Above about 0.5 mm. diam. the grains are invariably well rounded, below this they become sub-angular, and the smallest grains are quite angular.

The quartz usually contains numerous inclusions, regular, irregular, and acicular. The regular inclusions are frequently so numerous and large as to make up a considerable portion of the grain. The following minerals have been identified as inclusions:

Biotite	Rutile (yellow variety)
Muscovite	Apatite
(?)Iron Ores	(?)Sillimanite
Zircon	(?)Sphene

All of these occur as individual species in the heavy crops, except sillimanite and sphene. It is likely that many of the individual minerals in the heavy crops owe their presence to transportation in the quartz, and subsequent breaking up of the quartz.

An investigation according to the methods of Mackie²¹ of the relative amounts of quartz grains bearing each of the different types of inclusions was made, with the following results (Table VII).

TABLE VII.

Sample No.	Type of Inclusion				R + N	No. of Observ
	Reg.	Irreg	Acic	None	I + A	
F2	37	63	3	6	0.67	109
E5	40	55	6	4	0.72	105
L1	34	57	12	5	0.56	108
B7	54	34	6	5	1.47	99
H2	35	55	6	6	0.67	102
N3	27	66	7	0	0.37	100
D	24	18	7	3	1.08	52
G2	29	72	5	0	0.37	106

Localities of samples

F2—Collywell Bay.

H2—North Hylton

E5—Tynemouth Cliff.

N3—Hetton Downs

L1—Harton.

D—Elemore Hall

B7—Hylton Castle.

G2—Ferryhill.

Mackie's general conclusion for the rocks of the Moray district is that the Irregular and Acicular types of inclusion are characteristic of quartz grains derived from granitic rocks and that the Regular type and grains having no inclusions are characteristic of gneissic and schistose rocks. If this be universally true the ratios given in column 6 above for the Yellow Sands indicate a dual source for the quartz with a slight preponderance of grains from granitic rocks. The ratios of gneissic types to granitic types are of the same order throughout from north to south although there is some slight indication of a decrease of gneissic with respect to granitic types but this is neither regular nor indeed definite.

Viewed in reflected light all the grains have a surface like ground- or frosted glass. Combined with the rounding of the grains this may be taken as an indication of aeolian transportation. In itself rounding is not conclusive evidence of eolian wear as Galloway² has shown but in conjunction with other phenomena amongst which is this frosting of the grains it may be taken as indicating this type of deposition.

In thin sections of the more consolidated types of Yellow Sands many of the quartz grains show evidence of having been under strain. In various grains there is every gradation from those showing only slight strain-shadows between crossed nicols to those showing granulation and intricate suturing of the individual portions making up the composite grain (see Plate II figs 1 and 2). In addition to these there are composite grains made up of an aggregation of minute quartz grains, apparently derived from a quartz-schist (see Plate II fig. 3).

Rutile

Occurs in all localities

There are two distinct types of this mineral present in the Sands. One type is a dark, reddish-brown in colour, strongly pleochroic. It is usually in medium or large-sized grains, rounded or sub-angular in shape, many apparently being worn prisms. A few are worn geniculate twins, while in one instance polysynthetic twinning

was noted. The other type is amber-coloured and is usually smaller than the red type, it is non-pleochroic, rounded to sub-angular often prismatic.

In addition to these types there are small, irregular, usually angular grains with sub-conchoidal fracture, and of a brass-yellow colour. These are believed to be, in the main, broken fragments of the other types, although some may be original, having been transported in the quartz grains and subsequently freed, as already suggested.

Staurolite

Localities Collywell Bay and Hetton Downs

Occurs sparingly in medium-sized, sharply angular grains having toothed edges, and showing good cleavage, mean Ref Ind = 1.652 perfectly transparent, pleochroic with X=Y pale yellowish-brown, Z deeper yellowish-brown, moderate birefringence, biaxial positive figure usually indistinct.

Tourmaline

Occurs in all localities except Elemore Hall

Tourmaline is always very abundant in the localities in which it occurs. The grains are usually of medium size, and sub-angular to rounded. Occasional grains with well preserved outlines are met with. Both prismatic and basal grains are common. As is usual with tourmaline, the colour varies so much that it forms no criterion upon which to classify the grains. The commonest seem to be those with E colourless, greyish- or greenish-brown, or brown, and O dark-brown to black, in these the pleochroism is intense. Others have E pinkish-grey or brownish-pink, and O black or very dark brown. Much more rare are those with E pale straw yellow, and O dark red-brown, and E greyish-blue, and O indigo blue to black (usually moderate pleochroism).

Inclusions are fairly common, frequently arranged parallel to the "c" axis. They are too small to identify with certainty, but appear to be zircon, apatite, and (?) sillimanite or rutile needles.

PLATE II

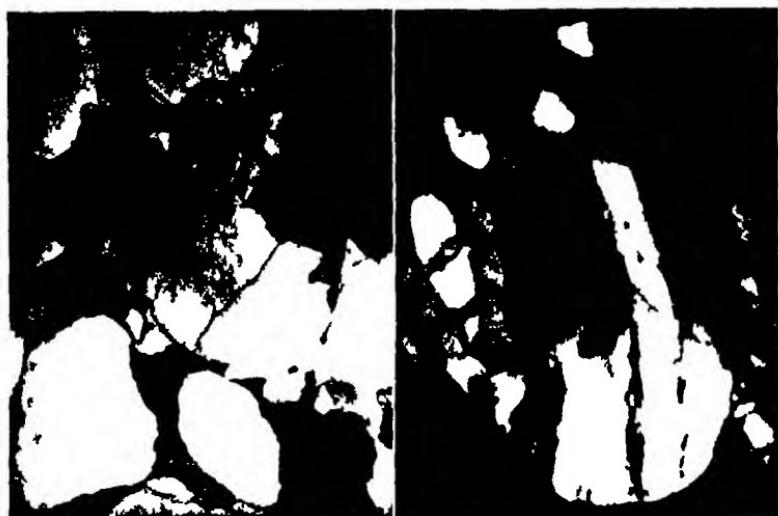


Fig. 1

Fig. 2

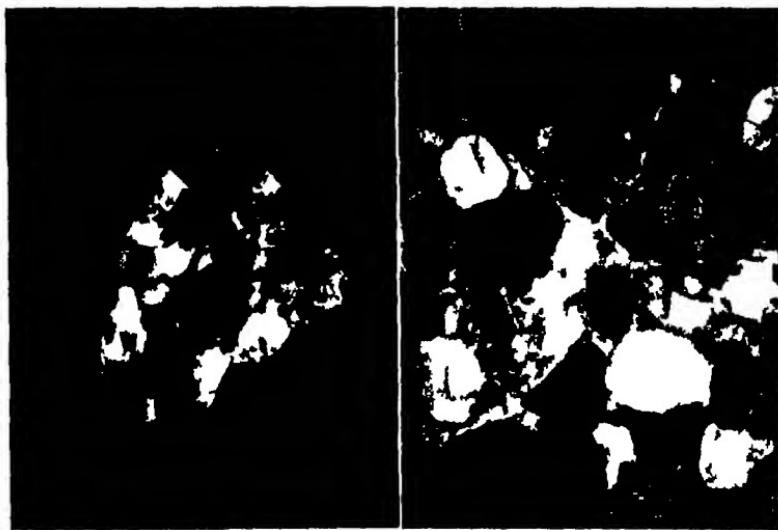


Fig. 3

Fig. 4

Zircon and (?) Xenotime.

Present in all localities except Elemore Hall.

Occurs in small to medium-sized grains, most of which are sub-angular to rounded, frequently prismatic. Occasional grains have their crystalline outline well preserved, in which case the forms (100), (110), (111), and (?) (311) may be seen. They are usually colourless, but occasional grains are seen which are yellowish in colour, often showing zonal structure, and being slightly cloudy in appearance. These may be xenotime, but spectroscopic examination could not be carried out.

In samples E₅, F₂, and G₂, zircons with a faint pink or purplish colour can be seen. Through the courtesy of Dr. W. Mackie I was able to examine the purple zircons which he has described,³¹ and I believe these to be of identical character.

Very rare grains with a faint green colour, rather patchy in distribution, were also seen. One of these, a basal section, was anomalously biaxial, with a small optic axial angle.

Both of these more rare types are described by Bosworth as occurring in the sandstones of the Scottish Carboniferous rocks.³⁴

Zonal structure is fairly common. Many of the grains contain numbers of inclusions, usually crystalline and euhedral, but not infrequently minute and rounded. The inclusions, when acicular, are often arranged with their long axes parallel to "c," but frequently have no definite arrangement.

All of the minerals described above correspond in a very striking manner, not only in species, which is, in fact, not a very reliable criterion, but in actual type with those described by Bosworth in the article cited above.³⁴

Bosworth found garnet, zircon, magnetite, tourmaline, rutile, staurolite, anatase, and barytes in the Scottish Carboniferous rocks. All of these are present in the Yellow Sands with the exception of barytes, which, however, has been found in the Lower Permian of Yorkshire by Lewis³⁵ and by Versey.³⁶

In itself this assemblage has little or no significance in determining the source of the Yellow Sands but when the types of each mineral are examined it will be seen that there is the strongest evidence for the belief that the Yellow Sands minerals were derived either from the Scottish Carboniferous or from the parent rocks of the Scottish Carboniferous.

The correspondence between the *silex*s of the two formations has already been pointed out. In each case a strong development of the dodecahedral cleavage in the garnets is notable. The tourmalines are characteristically brown with numerous blue and greenish grains and are frequently prismatic with traces of pyramidal terminations. The staurolite which occurs sparingly in both deposits is angular with toothed edges the teeth being large. Bosworth finds the same three types of rutile deep amber, brass or golden yellow and deep coloured in stout stumpy prisms with occasional geniculate twins those from the Carboniferous being angular or subangular in general and those from the Yellow Sands being subangular or rounded. He describes the anatase as being steel blue in colour while that of the Yellow Sands is brownish grey in each case the crystal outline is perfect which seems to point to secondary origin possibly from the decomposition of ilmenite.

Thin sections yield little information in such an investigation as this even where it is possible to prepare them. The two which it has been possible to make however bring out in a striking manner the association of the large rounded grains with the small angular ones (see Plate II fig 2). The granulation of the quartz has already been noted (p 442).

Comparison with sections of the local Coal Measure sandstones and the Millstone Grit of Northumberland demonstrates the great lithological difference between these and the Yellow Sands. The Carboniferous sandstones are made up of angular grains often smaller than those of the Permian, and the quartz only rarely shows strain shadows and never so far as the author has seen any granulation.

IV. Stratigraphical Relations of the Yellow Sands.

The opinions of the earlier writers on the question of the relations of the Yellow Sands to the Coal Measures have already been set forth (pp. 410-414) the consensus of opinion being that an unconformity exists between the two formations. This conclusion is amply confirmed by the new evidence which has been supplied by borings and sinkings passing through the Permian into the Coal Measures.

A study of the borings and sinkings which pass through the Yellow Sands shows that the Sands lie at different places upon Coal Measure strata of varying age. This has been well demonstrated by some of Dr. Hopkins' work on the correlation of the coal-seams of Durham. For example, at Seaham Colliery the Yellow Sands lie about eighty feet above the Grindstone Post, while at Horden Colliery about six miles to the south, they lie on the Upper Seventy-fathom Post, much lower in the series.¹²

Further evidence of the unconformity may be derived from the relationship of the Marl Slate to the Yellow Sands and the Coal Measures.

The Marl Slate is a bed of finely laminated, calcareous and magnesian shale, varying from one to twelve feet in thickness. At places (e.g. Hetton Downs) the lower part is a stiff brown clay. Normally, the colour varies from the ordinary yellow of the Magnesian Limestone to a dark grey. It occasionally contains pyrite and traces of manganese. Towards the base it is sandy, and it becomes more pure towards the overlying Lower Magnesian Limestone, the amount of sand varying from about 40 per cent. to less than 5 per cent. In some places there appears to be an intercalation of the Marl Slate (or of similar material) with the Lower Limestone on the one hand, and the Yellow Sands on the other.

There has never been any doubt as to the inclusion of the Marl Slate in the Permian, and of its equivalence with the Kupferschiefer of Germany, the fossil assemblage being practically identical in the two formations.

The occurrence of the fossils is sporadic, certain localities having yielded a much more varied assemblage than others, while many localities seem to be quite barren.

While, as stated above, thin beds of similar composition and appearance to the Marl Slate occasionally occur in the Lower Limestone, and in the Middle Limestone, the bed which goes by the name of the Marl Slate or Fish Bed always occurs under the Lower Limestone, and is conformable with it, where the two are not separated. In several localities, however, beds of Yellow Sands occur between the Marl Slate and the Lower Limestone (e.g. Tynemouth Cliff). It seems, therefore, that the Marl Slate and the Yellow Sands were in part contemporaneous, if not entirely so, and that the Yellow Sands are consequently unconformable with the Coal Measures, and are correctly included in the Permian.

V. Comparison with the Lower Permian of other Areas.

(a) Yorkshire.

Passing southwards along the outcrop of the Permian the total thickness diminishes. In Durham it is about 1,200 feet;²⁶ in Yorkshire near Pontefract and elsewhere, the limestone becomes thinner and the Marl Slate a little thicker, the total thickness being 430 to 570 feet; while in Nottinghamshire the thickness at the outcrop diminishes considerably, being only 110 to 150 feet,²⁷ and eventually dying out altogether.

Running in an E.—W. direction across the south of Durham and the north of Yorkshire is an anticline which brings near to the surface the Lower Carboniferous rocks. Against this ridge the Yellow Sands appear to die out, but similar beds reappear farther south, in Yorkshire. Here they occur in isolated patches, and are thinner, the thickness rarely reaching twenty feet.

In the south of Yorkshire the outcrop becomes continuous, and breccias and marls form the lowest beds of the Permian. Jukes-Browne, in his "Building of the British Isles," takes this as an indication that the southern shore of the Permian sea lay in this direction, the breccia

being derived in part from the Coal Measures, and possibly in part from the Charnwood rocks.

Versey²⁸ finds that in the concealed coalfield area of Yorkshire there is a definite arrangement of the Yellow Sands into parallel belts, and that at the south-eastern end of each belt the limestone is underlain by a black marine shale. Whether the shale is contemporaneous with the Yellow Sands or not, he leaves *sub judice*. In Durham the author has been able to find no such parallel arrangement, but believes, as already pointed out (p. 448), that the Marl Slate is in part contemporaneous with the Yellow Sands.

Coarse conglomeratic facies occur locally at Conisborough and Castleford in Yorkshire, and these are attributed by Versey to local flood-washes (*loc. cit.*). Only in one place in the Durham area is there any record of such a conglomerate. The sinking at Blackhalls Colliery passed through one foot six inches of a conglomerate which the late Dr. Woolacott described verbally to me as being composed of rounded quartz, chert, and Carboniferous limestone pebbles, with encrinite stems (*remanié*). At Tynemouth Cliff at the junction with the Coal Measure sandstone there is a layer of the Yellow Sands about one foot in thickness, containing a few quartz pebbles (see p. 419), but this cannot be called a conglomerate.

The Durham Yellow Sands thus appear to be, if anything, more uniform in their megascopic characters than those of Yorkshire described by Versey. According to this author the sandy beds in the two localities resemble each other closely. In each case the beds are made up of incoherent quartz sand, with rounded and "polished" grains (? frosted). The quartz grains with the irregular type of inclusion predominate in Yorkshire as in Durham, but unfortunately no quantitative results are given. Versey also notes the presence of grains of quartzite, and strained quartz grains, while chert is evidently present in greater amount than in Durham. The felspars are identical in the two areas.

A comparison of the heavy minerals shows some slight differences in species, as follows

	<i>Durham</i>	<i>Yorkshire</i>
Cubic	Garnet — Magnetite	Garnet Fluorspar Magnetite
Tetragonal	Rutile Anatase Zircon —	Rutile Anatase Zircon ? Cassiterite
Hexagonal	Apatite	Apatite
Trigonal	Tourmaline Ilmenite ? Haematite	Tourmaline Ilmenite —
Orthorhombic	Staurolite —	Staurolite Barytes
Monoclinic	Biotite — Muscovite —	— Monazite — Epidote

The types of those minerals which occur in both areas are similar, except that the garnets present a greater variety in the north. Versey believes that the Millstone Grit and Coal Measures supplied the material for the Lower Permian of Yorkshire, with the possibility of some of the material having been derived from the Carboniferous Limestone.

(b) *West of the Pennines*

Two main areas of Permian occur on the west side of the Pennines, one in Cumberland, Westmorland, and North Lancashire, and the other in the Manchester and Stockport area of South Lancashire.

In the northern area, according to Goodchild quoted by Sherlock,²⁹ the succession is :

Upper	Red marls and shales—probably Triassic. Magnesian Limestone—0 to 10 feet. Hilton Shales—up to 150 feet—Marl Slate.
Lower	Copper red sandstones. Upper Brockram. Penrith Sandstone. Lower Brockram.

In the Manchester area Hickling³⁰ gives the following classification of the deposits :

- Bunter Sandstones.
- Permian Marls.
- " Permian Sandstones." (a) True Permian.
(b) Upper Coal Measures.
- Coal Measures.

Correlation of the Durham and Yorkshire deposits with those of the west side of the Pennines presents considerable difficulty. Sherlock²⁹ discusses at some length the question of the correlation of the thin Magnesian Limestone of the Cumberland—Westmorland area with the Magnesian Limestone of Yorkshire, and finally reaches the conclusion that the limestone in the north-western area is the equivalent of the Lower Limestone of Yorkshire, while not overlooking the possibility suggested by Geinitz³¹ that it may be Upper Zechstein, that is, Upper Magnesian Limestone of Woolacott.

With regard to the beds underlying the Magnesian Limestone series, Sherlock believes it to be possible that these beds, which Goodchild regarded as *Rotliegende* (i.e. Lower Permian), may actually belong to the Upper Coal Measures, as does the greater part of the "Rotliegende" of the Midlands. If this is not the case, there

are two other possibilities, according as we accept the Magnesian Limestone as the equivalent of the Upper or the Lower Magnesian Limestone of the eastern area. If the Cumberland Limestone is the Upper Magnesian Limestone, then Sherlock supposes that the underlying arenaceous and conglomeratic beds include an equivalent of the Lower Magnesian Limestone of Yorkshire and Nottinghamshire'. In the other case, the Penrith Sandstone and the Brockrams, he says, must have been formed "during part of the interval represented elsewhere by the great discordance between Carboniferous and Permian Trias".

While a discussion of this question is not entirely relevant to this paper, it may be said that the lithological characters of these deposits appear to favour the last opinion rather than the first. The presence of thick beds of conglomerate—the Lower Brockram reaches 1,500 feet in thickness in places—and of the Penrith Sandstone with its millet-seed grains, points to accumulation under terrestrial conditions, with accompanying violent erosive action.

In the Manchester area the Permian Marls contain numerous thin bands of "highly calcareous marls" (Hickling, op. cit., p. 10), these bands being rarely more than two or three inches in thickness. H. B. Geinitz examined the fossils from the marls, and classified them as Upper Zechstein, but with this conclusion Sherlock does not find himself in agreement, preferring to regard them as equivalent to the Magnesian Limestone series of Cumberland and Westmorland, and consequently to the Lower Zechstein (Lower Magnesian Limestone of Yorkshire).

Of the sandstones underlying the Permian Marls Hickling says:

"The 'Permian Sandstones' probably include some strata of Upper Permian age, but the thicker masses of this sandstone are in the main considerably older, being possibly the equivalents of the Keele Sandstones of North Staffordshire."

An isolated patch of Permian occurs at Skillaw Clough, Bispham, Lancs. Here "six feet of Magnesian Limestone rests on thirty feet of marls and shales that have yielded Zechstein fossils. Below the Marls are thirty-five feet of soft red sandstone resting on Millstone Grit. In this case we can assign the rocks to the Magnesian Limestone series." (Sherlock, op. cit., p. 40.)

Miss M. Workman has examined these rocks petrographically, and finds the following minerals:

Pyrite, magnetite, garnet, rutile, anatase, xenotime(?), zircon, tourmaline (grey and brown), ilmenite, hæmatite, hypersthene, muscovite, epidote, chlorite, and monazite.

She concludes that the sandstones were derived from the Millstone Grit.³²

It is thus difficult to find any real grounds for making a close correlation between the Yellow Sands and any of the Permian strata west of the Pennines, although there is a possibility that the sandy facies at the base of the Permian Marls in the Manchester area, and the red sandstone of Skillaw Clough, are equivalent in point of time to the Yellow Sands.

(c) Germany.

In Germany the Upper Permian, or Zechstein, agrees very closely with that of the north-east of England.

The divisions given by Kayser³³ are as follows:

Upper Zechstein

Upper clay, with newer gypsum and dolomite intercalations.

Middle Zechstein

Stinkschiefer and Great Dolomite.

Older gypsum, rauchwacke, and ashes.

Lower Zechstein

Zechstein Limestone.

Kupferschiefer.

Zechstein conglomerate.

The fossil assemblage of the Kupferschiefer coincides to a remarkable degree with that of the Marl Slate, and on these grounds, as well as those of stratigraphical position and lithological character, there need be no hesitation in correlating the two beds.

The Zechstein conglomerate is described by Beyrich and Eck³⁴ as

A coarse, sandy or conglomeratic deposit, seldom over three feet, and at most six feet thick, containing pebbles of decomposed greywacke varying from the size of an egg to that of one's fist, and also sparse quartz pebbles, but never pebbles of eruptive rocks of the Rotliegenden. It forms in the southern Harz from Steina to Sangerhausen the unfailing underlying bed of the Kupferschiefer.

In the Mansfeld area it is described³⁵ as

"A layer of rather coarse, grey, peculiarly round-grained sandstone, varying from 0.02 to 2.0 metres in thickness, in which Beyrich has distinguished the habit of the 'Zechstein conglomerate,' in spite of the fineness of the material."

The name Weissliegende or Grauliegende has been used for this sandy phase, whose description coincides closely with that of the Yellow Sands. It was formerly included as a bleached phase of the "Upper Rotliegende." The authors of the Memoir quoted,³⁶ however, state that the deposit always accompanies the Kupferschiefer even where it lies unconformably on the Rotliegende, and hence that it should be included in the Lower Zechstein.

It is evident that this deposit is in every way analogous in stratigraphical position, and probably in mode of origin to the Yellow Sands, and should therefore be correlated with them.

VI. Summary and Conclusions.

Summarizing the evidence which has been presented, the Yellow Sands may be described as a loosely-cemented, or incoherent sand occurring at the base of the Magnesian Limestone series in Northumberland and Durham. The thickness varies rapidly and irregularly from 0 to 150 feet, while its distribution along the outcrop and beneath the Magnesian Limestone is sporadic, and it disappears completely in the south of Durham against a ridge of the Lower Carboniferous.

It is commonly yellow in colour, but there are irregular areas of dark brown, white, grey, and bluish colour. The yellow colour is probably original, and the variegation due to secondary changes. In many places it is false-bedded after an æolian type, but occasionally it shows what seems rather to be current-bedding. There is little evidence to show that this current-bedding occurs more frequently at the top of the Yellow Sands rather than at the bottom.

Elutriation shows that there are two grades which are predominant, one between 0.05 mm. and 0.15 mm. diam., and the other, less definite, between 0.6 mm. and 0.8 mm. diam. This is taken to indicate æolian transportation of the grains.

The heavy minerals agree in species and type with those of the Scottish Carboniferous rocks. The quartz grains are frosted, and the larger ones well rounded, while the inclusions contained in them indicate a dual granitic and metamorphic source, according to the criteria of Mackie.

Intercalations of Marl Slate material, Yellow Sands, and Lower Bedded Limestone (lower part) are seen occasionally, and indicate that the three deposits were in part contemporaneous, although the general succession in this area is, no doubt, from Yellow Sands through Marl Slate to Lower Limestone.

The Yellow Sands are held to be the equivalent of the Lower Permian of Yorkshire and of the Zechstein conglomerate of Germany.

It is concluded that the Yellow Sands were mainly a deposit of sand on the shore of the Permian sea, the

material being derived partly from the Carboniferous sandstones in the immediate vicinity, and probably partly from an area to the north in which sandstones and some granitic and metamorphic rocks were undergoing denudation. While the Yellow Sands were being deposited on the shores and in the country immediately behind, the Marl Slate was being laid down as a calcareous mud in lagoons fringing the shores.

It is likely that the land had been denuded to a state approaching peneplanation, and that at this time a renewal of movement was just commencing. With the sinking of the coast the lagoons were gradually invaded by the sea which deposited the Lower Limestone. While these movements were in progress the Yellow Sands would occasionally be blown into the lagoons, giving rise to the intercalations of sand with shale and limestone now found.

The author wishes to thank Professor G. Hickling of Armstrong College, Newcastle-upon-Tyne, under whose guidance this work was carried out, for continual advice and constructive criticism, and also Dr. J. G. Kellett, now of the West Riding County Education Authority, who collaborated in the earlier field-work.

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EXPLANATION OF PLATES

Plate I

Map showing outcrop of Yellow Sands and contours on surface of Coal Measures

Fig 1 Specimen of consolidated Yellow Sands showing nodular structure due to segregation of calcite About two thirds natural size

Fig 2 False bedding in Yellow Sands at Claxheugh

Plate II

Fig 1 Thin section of consolidated Yellow Sands showing unstrained and slightly strained quartz grains

Fig 2 Similar section showing large rounded grain of quartz with intense strain shadows Note small sub-angular grains set in matrix of calcite

Fig 3 Grain of quartz schist

Fig 4 Angular and sub-angular grains of quartz and microcline with calcite cement

All of the above figures on Plate II photographed between crossed nicols Magnification x50

CHARACTERISTICS OF POLAR AND NON-POLAR CHEMICAL REACTIONS

By W A WATERS, M.A., PH.D.

It is now commonplace to classify molecules after the manner of G N Lewis into Electrovalent compounds like sodium chloride and Covalent compounds like chlorine. Substances like sodium chloride are in reality *Ion-Pairs* held together by nothing more than the electrostatic attraction between the individual ions, and there is no intrinsic difference between their "dissociated" and "undissociated" states apart from the independent mobility of separated ions and a certain amount of electrostatic deformation of each ion in an ion-pair. Ion-Pairs, however, cannot be distinguished by any direct test from the essentially different Covalent molecules, for even the latter can possess permanent electrical dipole moments and may dissociate so as to give ionized radicals.

Covalent molecules, which do not contain sufficient electrons for each atom to acquire its own exclusive octet of electrons, are constituted of atoms which complete their stable electronic octets by the process of electron sharing—two electrons forming one chemical bond. Whereas Ion-Pairs can only react by the separation of their pre-existing ions, and interchange of these with other ions, the Covalent compounds can react either by Symmetrical Fission into free *Neutral* radicals—



or by Unsymmetrical Fission into a Positive Ion containing only six electrons and a Negative Ion with a complete octet:—



Most chemical reactions, even in Organic Chemistry, involve ionization, a fact remarked on by Lapworth in 1901.¹ These reactions can be interpreted by the modern theories of Polarity (as developed by Lapworth,

Robinson, Ingold and others), which start from the practicability of classifying atoms, and the compound radicals of organic chemistry, into Anionoid and Cationoid reagents according to whether they tend to act as Anions like Cl^- or Cations like Na^+ .

There are known, however, some chemical reactions which occur under conditions in which ionization would seem very improbable, and in many such reaction mixtures no ions can be found. These changes may be *Non-Polar* reactions, in which are concerned only electrically neutral radicals and molecules. Definite characteristic circumstances can be applied to differentiate between the polar and the non-polar reactions.

Chlorine may be taken as a typical covalent molecule that is capable of acting both in polar and in non-polar fashion. It is well established that the *dissociation* of the dry gas by heating, or by irradiating with ultra-violet light, is decomposition into neutral atoms—possibly activated atoms—but still not ions. The modern conception of this change³ is to suppose that at a particular instant the molecule acquires sufficient energy to disrupt the electron pair, one electron thereby becoming planetary to each atom only : the normal rotational (or other) kinetic energy of the molecule then results in the spatial separation of the neutral atoms. The change is, like any other light absorption or emission, a discontinuous one, instantaneous in occurrence. That is to say, it is of *Explosive* character.

The free neutral atoms are capable of reacting instantly with neutral molecules on mere collision :—

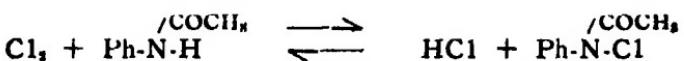


In this way are propagated rapid chain reactions.

Many other atoms act similarly, as for example sodium, which, in the state of the monatomic vapour, can decompose halogens and both organic and inorganic halides.^{3,4}

Polar reaction of chlorine occurs, in contrast, in solutions at moderate temperatures and requires no extraneous supply of light or heat energy. The "positive" and "negative" natures of the reaction

products are best shown through the chemical reactivities of the substances produced, as in the case of the reaction with acetanilide :-



Polar dissociation is promoted by the presence of ionizing solvents (e.g. water) which lessen the magnitude of the inter-ionic attraction once the incipient ionization has occurred, and more particularly by *polar catalysts* which promote the separation of the free ions. Thus sodium hydroxide promotes the dissociation



because it supplies a high concentration of OH^- ion, which will combine readily with the reactive Cl^+ ion to give the stable molecule H-O-Cl .

One can say to-day that the polar dissociation of a covalent bond is brought about by the *Induction of Electrical Polarity* (i.e. Electrical Dissymmetry) by vicinal electrical fields—from adjacent molecules in any reaction mixture, or perhaps by polar groups situated elsewhere in the same molecule.

In Organic Chemistry it is evident that the carbon-carbon linkage, like the chlorine-chlorine linkage, is capable of dissociation either in polar or in non-polar manner. For example, hexaphenyl ethane dissociates both in polar solvents like liquid sulphur dioxide, in which it gives conducting solutions, and in non-polar solvents like benzene, giving different types of absorption spectra in the two solutions.⁵ For the existence of the two ions the properties of derived compounds—carbonium salts and metallic aryls—bears evidence. For the existence of the free neutral radicals there is again direct evidence from the marked way in which triphenylmethyl will *combine* with other free neutral radicals.



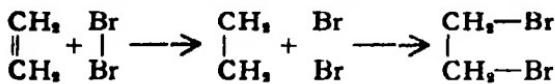
* For the relative stability of the "free radical" NO, which contains an *odd* number of electrons, cf. Pauling, J.A.C.S., 1931, 53, 3230.

Since the transitory existence of the free neutral methyl and ethyl radicals (prepared by *thermal* decompositions) has been demonstrated by Paneth⁶ there is no reason to suppose that any hydrocarbon radical should be incapable of acting in this same non-polar manner.

Of non-polar types of reactions, *Combination* of two neutral radicals each containing seven electrons and eventually gaining one more to complete the octet, is characteristic and apparently occurs instantaneously on the mere collision of the two particles.

Its reverse, the *Dissociation* of a covalent molecule into neutral radicals, seems to be brought about *only* by thermal or photochemical activation and not by catalysts.

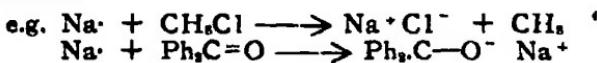
If the carbon-carbon single bond can be broken to give two free neutral radicals, then the carbon-carbon double bond could be partly broken to give two free valencies and a single bond. Similarly a triple bond could be broken to give two free valencies and a double bond. Consequently the original mechanism, due to Kekulé, of addition to an unsaturated compound is still a valid one.



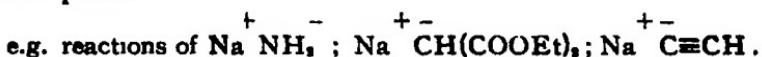
For the non-polar action of photochemical halogen addition to unsaturated compounds, experimental evidence⁸ indicates that the halogen molecule must first be activated (*i.e.* dissociated) by absorbed light energy before it can react with the organic molecule. The neutral halogen atoms thus produced may, however, add on independently and not simultaneously. Consequently, if free rotation about a single bond in the reacting organic substance be admitted, one can explain both Cis-Trans isomerization of olefines and the Trans addition of substituent groups.⁹ If the organic compound also can be activated directly by light, then such photo-polymerization as of cinnamic acid to the truxilllic acids, or anthracene to dianthracene, can be explained. In the latter case the dissociability of the valency bond in the central benzenoid ring of the corresponding diphenyl-anthracene has been proved conclusively.¹⁰ This photo-polymerization to yield ring

compounds is a different type of process from the chain polymerization recently investigated by Staudinger and others.¹¹

Free metals are capable of acting like the halogen atoms and combining with neutral radicals. Conversely neutral radicals are produced by the thermal dissociation of metallic alkyls.⁶ When a metal like sodium combines with a free monovalent radical there is a transfer of one electron from the metal, and consequently the reaction is more properly the action of the single electron. Metals producing free radicals

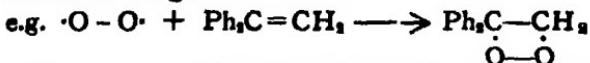


act quite differently from metallic ions and salts with which mere replacement of one ion by another radical takes place.



Sodium metal, in giving a single electron to the double bond, can, like a halogen atom, bring about cis-trans isomerization¹² probably by the same mechanism. The free radical NO is also an inverting agent, as in the oleic acid—elaidic acid change.

In classifying free neutral radicals, R. Kuhn¹³ has considered paramagnetic character to be diagnostic of odd, unpaired, electrons. Now oxygen gas is almost unique in being a paramagnetic molecule, and actually oxygen does have the characteristic reactions of the free neutral radicals. It combines with metals and free radicals to give peroxides, such as $\text{Ph}_3\text{C-O-O-CPh}_3$, and will add on to olefines to form moloxides, probably containing a four-membered ring.



Further, auto-oxidations are very frequently photochemical reactions.

One of the forms of Active Nitrogen may have similar, neutral, free-radical type of structure.⁷

The action of dissociation—the reverse of the non-polar addition—might be expected to be non-polar when brought

about by heat, light, or mechanical shock in the absence of catalysts. The explosive decompositions of azides and of free diazo compounds are of this character. For example Thiele¹¹ found that azomethane, $\text{CH}_3\text{-N}=\text{N-CH}_3$, decomposed spontaneously on heating, giving gases among which H_2 and C_2H_4 were present only in small proportion; ethane therefore being the chief product, a fact verified by Ramsperger,²¹ who also showed this action to be capable of photochemical activation. Wieland,¹⁵ developing this, has obtained more definite evidence for the production of free radicals on thermal decomposition of azo compounds, for acetyl-azo-triphenylmethane on decomposition in an inert solvent gives triphenyl methyl, and in presence of air (oxygen) yields also triphenylmethyl-peroxide and a trace of diacetyl peroxide. Very often in the reactions of diazomethane and of diazoacetic ester there is evidence of a two-stage process; addition, probably by a polar mechanism,¹⁶ being followed subsequently by elimination of nitrogen gas. The Buchner-Curtius reaction and the Schlotterbeck reaction¹⁷ can be used to exemplify this.

If one thinks of the elimination of nitrogen as $\cdot\text{N}=\text{N}\cdot$ being the non-polar process, then with this same group of reactions must be classified the elimination of nitrogen from syn-diazo compounds, as used so extensively in the laboratory in the reactions associated with the names of Bamberger, Sandmeyer, Pschorr and others.



In connection with this it may be noted that diazonium salts, which could not decompose in this way, are much more stable than the diazo compounds with which they are in tautomeric equilibrium. The function of the cuprous salts in the Sandmeyer reaction may be to give covalent copper co-ordination compounds which could decompose in this non-polar way.

Analogous non-polar decomposition has been proved to occur with aldehydes and ketones, which on heating yield carbon monoxide—a molecule isosteric with that of nitrogen. This reaction is a photochemical one, occurring

with light of wave-lengths below the pre-dissociation limit,¹⁸ which is the stage at which dissociation of the molecule may commence. No ions are formed, and the free radicals may have no appreciable independent existence, as they combine with each other too rapidly for molecular collisions to intervene and make it possible for mixed products to be formed. Thus photolysis of a mixture of benzaldehyde and acetaldehyde yields only carbon monoxide, benzene and methane, and not hydrogen, diphenyl, or ethane.

The same rapid union of the free radicals would be anticipated in the decomposition of the azo compounds.

The classification of chemical reactions into polar and non-polar groups is not so easy in the case of substitution as in the cases of addition or dissociation. Collisions of free atoms or radicals with covalent molecules can undoubtedly bring about substitution, provided the colliding particles have already sufficient energy of activation to bring about the disruption of the covalent bond in the original molecule.⁴ Halogen molecules can be activated either to atoms or to ions, and consequently the nature of halogen substitution is not discernible without thorough examination of experimental conditions. The action of chlorine on methane in sunlight, giving methyl chloride, is possibly non-polar, and preceded by photochemical dissociation of the chlorine. The reaction between chlorine and trichloro-bromo-methane certainly is of this type.¹⁹ The reaction between benzene and chlorine to give chlorobenzene in contrast is probably polar, for it occurs most easily in the presence of polar catalysts and at a low temperature. The photochemical action between chlorine and benzene indeed affords a sharp contrast, for the hexachloride $C_6H_6Cl_6$ is produced instead—the typical non-polar addition to an olefine.

Perhaps photochemical substitutions could be regarded as non-polar and all others polar in type. In the case of toluene it might be possible to make a rough distinction in this way between the high temperature, photochemical, side-chain substitution and the low temperature, catalysed, nuclear substitution.

From the above considerations it appears that in general photochemical activation may be concerned with non-polar change, in which odd, unpaired, electrons are concerned. In the same way the excitation of any atom to emission of a characteristic spectral line involves the movement of one electron from one quantized orbit to another; the light being emitted on the return of the atom from the less stable to the more stable form.

In organic compounds at least, all the optically excitable electrons of the constituent atoms are involved in the formation of covalent bonds, and hence emission of light, as in the phenomenon of fluorescence, must be concerned with the re-formation of stable valency bonds.²⁰ Fluorescence is invariably associated both with chemical reactivity and with "pre-dissociation" of a molecule. Since all fluorescent organic compounds belong to types which can give free neutral radicals either by dissociation or by addition of alkali metals, may not the emission of fluorescent radiation be diagnostic evidence of non-polar decomposition of a covalent bond, the actual light emission occurring some 10^{-9} seconds later when the free radicals unite together again with loss of the extra acquired energy in the form of radiation?

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P

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1931.

Nov. 23rd—"Characteristics of Polar and Non-polar Chemical Reactions." By Dr. W. A. Waters.

,, 27th—"Algebraic Curves and Surfaces with assigned singularities." By Prof. T. R. Hollcroft.

1932.

Jan. 25th—"The Scope of Mathematics." By Dr. H. P. Mulholland.

,, 28th—"The Creep of Materials under Stress." A discussion.

Feb. 3rd—"A Note on Images in Hydrodynamics." By Prof. T. H. Havelock.

,, 3rd—"Symbolic Methods of Integration." By Mr. J. L. Burchnall.

,, 19th—"New Aspects of Gaseous Combustion." By Dr. R. Spence.

,, 22nd—"The Scope of Biology." By Dr. B. M. Griffiths.

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